Interpreting Circularity in Green Building Rating Systems Using the 10R Framework: A Comparative Analysis of LEED, BREEAM, GREENSHIP, and BGH

JSACE 2/40

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Received 2026/02/02

Accepted after revision 2026/07/30

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https://doi.org/10.5755/j01.sace.43789

Abstract

Buildings and the construction sector are among the most significant contributors to global resource consumption. The emergence of Green Building Rating Systems (GBRS) is driving more sustainable construction; yet, most GBRS still lack explicit end-of-life considerations and do not indicate which circular-economy strategies their indicators support. This study interprets circularity in GBRS by applying the 10R Framework–Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Recover–in leading international and national GBRS. A terminology-based analysis based on qualitative content analysis was conducted by mapping indicators from four GBRS (LEED BD+C (v.4)), BREEAM New Construction (v.7), BGH *Tahap Perencanaan*, and GREENSHIP New Building (1.2)) onto the 10R circularity framework, using both explicit and implicit indicator descriptions. The frequencies and credit weights of each R-strategy were analyzed linguistically and normalized to percentages for comparison and evaluation of how thoroughly and in what ways each GBRS embeds circular economy principles. This study shows that in LEED BD+C (v.4), BREEAM New Construction (v.7), BGH *Tahap Perencanaan*, and GREENSHIP New Building (v.1.2), "circularity" is defined almost exclusively through up-front design thinking (R1) and measurable resource cuts (R2), with downstream loops (R3–R9) remaining marginal and end-of-life strategies receiving virtually no credit.

Keywords: 10R framework; circular economy; circularity; comparative analysis; green building rating system.

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Journal of Sustainable Architecture and Civil Engineering
Vol. 2 / No. 40 / 2026
pp. 6-24
DOI 10.5755/J01.SACE.43789

Introduction

According to the World Green Building Council (2019), buildings account for 39% of global energy-related carbon emissions, with operational energy responsible for 28% and embodied carbon for the remaining 11%. To address these environmental challenges, several Green Building Rating Systems (GBRS) have been introduced to promote more sustainable construction practices (Ade & Rehm, 2020). However, most GBRS do not explicitly address end-of-life (EoL) considerations or specify which circular economy (CE) strategies each indicator supports (Giarma et al., 2025). This lack of explicit alignment with circular principles creates ambiguity regarding how far the current GBRS actually promotes sustainability in green building practice (Giarma et al., 2025).

CE is defined by ISO 59004 (2024) as an economic system that maintains a circular flow of (i.e., material or component) to support a more sustainable development (ISO, 2024). CE offers a regenerative alternative to the linear "take–make–dispose" model that still dominates construction (Ellen MacArthur Foundation, 2024). In a circular economy, resources are designed and managed to minimise resource input, waste, emissions, and energy leakage by slowing, closing, and narrowing material and energy loops (Ellen MacArthur Foundation, 2024). In this study, circularity is therefore understood as the extent to which building-related resources, components, and materials are kept at their highest possible value for as long as possible through strategies that reduce virgin resource use, extend service life, enable disassembly, and support high-value recovery at EoL. Yet, despite the prominence of GBRS in steering design and construction decisions, it remains unclear which specific circular strategies they incentivize, how strongly, and where important gaps or trade-offs emerge (Giarma et al., 2025).

To interpret how GBRS incorporates circular economy strategies in a more systematic way, this study adopts the 10R framework by Potting et al. (2017) as a "clear and nearly exhaustive representation of existing CE strategies" (Giarma et al., 2025). The framework spans upstream strategies such as Refuse and Rethink, through classical approaches like Reduce and Reuse, to downstream options such as Recycle and Recover (Potting et al., 2017). In the construction sector, the 10R framework has a potential in assessing as well as assisting the implementation of circular economy within building practices, alongside other methods. A study combined the use of 10R framework with Life Cycle Assessment (LCA), in which LCA was used to quantify environmental impacts across a building's life cycle stages and the 10R framework analyzed the application of circular strategies within each stage (Petrovic et al., 2025).

This study focuses on using the 10R framework against several GBRS, specifically the new construction category as the most common and recognized across the global GBRS. The study chose 2 mature, internationally established schemes (LEED, BREEAM) and emerging, context-specific systems in a rapidly developing tropical economy of Indonesia (BGH, GREENSHIP). LEED and BREEAM are widely adopted benchmarks that strongly influence global sustainability standards in building design and construction, while GREENSHIP and BGH reflect Indonesia's national priorities, regulatory context, and tropical climatic conditions. Analysing these four systems in parallel enables a cross-context comparison between international and national GBRS, to reveal how circularity is interpreted and operationalised across different contextual settings.

Given the limited analysis of how circular–and therefore sustainable–green building rating systems (GBRS) actually are, this paper aims to examine how circular economy strategies are embedded within selected GBRS using the 10R framework, while responding to broader concerns in the literature that building circularity assessment remains fragmented across indicators, frameworks, and levels of analysis (Khadim et al., 2025). To address this aim, the study adopts the 10R Framework–Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Recover–as a comprehensive interpretive tool for evaluating circularity (Potting et al., 2017). Circularity is interpreted for the four selected GBRS (LEED BD+C, BREEAM New Construction, BGH *Tahap Perencanaan*, and GREENSHIP New Building) by mapping their

indicators against the 10R hierarchy, thereby revealing which circular strategies are most strongly embedded, which are marginal or absent, and how this distribution differs across international and Indonesian rating systems.

Materials and Methods

The research framework for this study (Fig. 1) began with delineating the scope of the GBRSs whose contribution to circularity would be examined. First, the 10R framework was synthesised from the literature and adopted as a comprehensive, hierarchical model for assessing circularity. GBRSs were then purposely selected based on their category, structure, and contextual characteristics. For secondary data collection, official documentation for each selected GBRS was retrieved from the respective websites, and all indicators and sub-indicators, together with their textual descriptions, were systematically extracted and categorised.

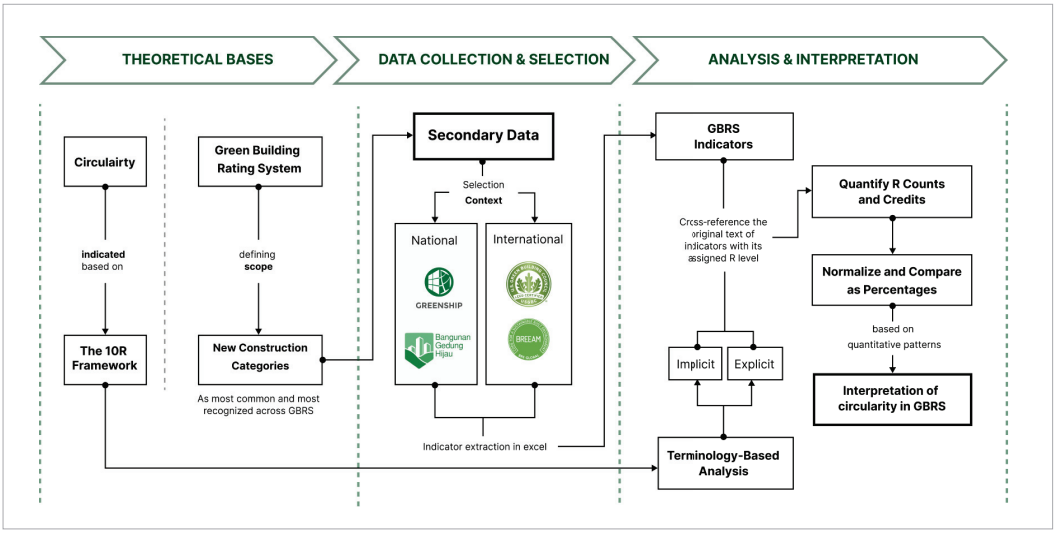


Fig. 1
Research Framework

The compiled indicators were subsequently mapped onto the 10R framework, quantified in terms of counts, credits, and normalised percentages across systems, and finally interpreted through both quantitative patterns and qualitative, terminology-based readings of the original indicator texts.

The 10R Framework as a Model for Circularity Assessment

The 10R Framework is arguably the most comprehensive model used to interpret circular strategies across the life cycles of materials, products, and systems. It extends beyond traditional concepts such as the 3R (Reduce, Reuse, Recycle) and 6R frameworks, offering a holistic, more hierarchical approach to implementing the circular economy (CE). Originally defined by Potting et al. (2017), this framework introduces ten R-strategies–Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Recover–which collectively provide a spectrum of interventions for resource efficiency and waste minimization throughout the life cycle of a product or building.

The 10R framework illustrates the systemic departure of the circular economy from the traditional linear model of "take–make–dispose" (Fig. 2). In a linear economy, resources are extracted, transformed into products, and ultimately discarded, resulting in material loss and environmental harm. By contrast, each "R" in the framework represents a circular strategy that interrupts this linear flow. Refuse (R0) and Rethink (R1) challenge the very premise of consumption by eliminating unnecessary demand or reimagining product use, while Reduce (R2) counters the inefficiency of linear production through resource optimization.

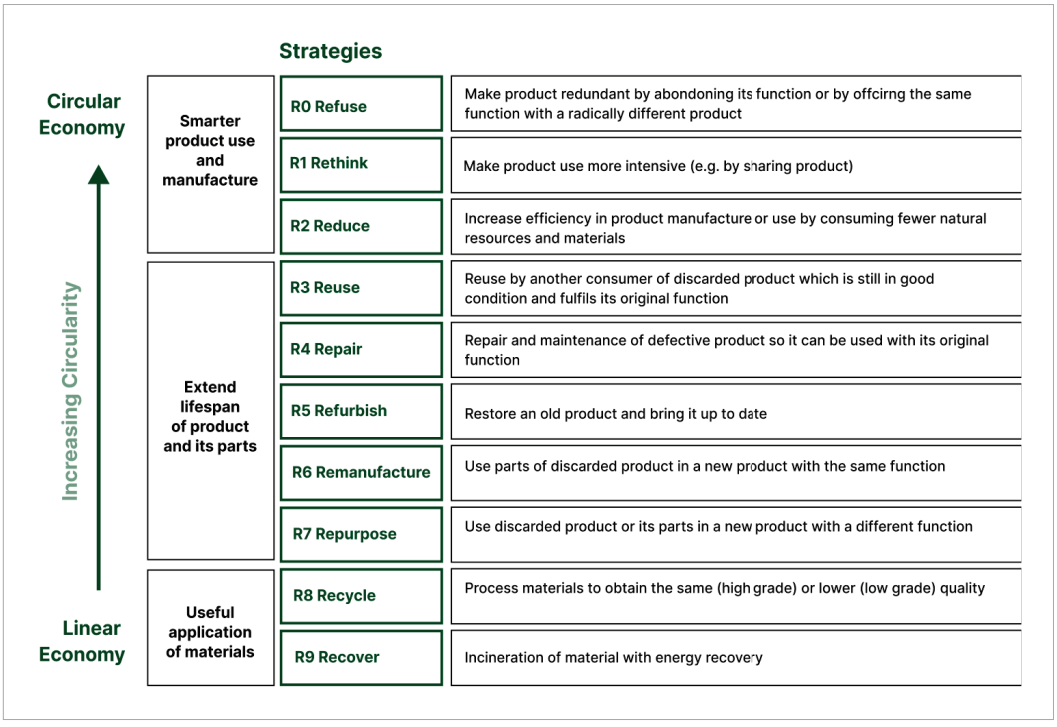
Table 1

The R Framework Development

Aspect	Early (no formal R)	3R	6R	10R
Initiator, Year	(United Nations, 1972)	Officially by Japan at the G8 Summit (Ministry of Foreign Affairs of Japan, 2004)	(Jawahir & Bradley, 2016)	(Potting et al., 2017)
The R framework	-	3R: Reduce; Reuse; Recycle	6R: Reduce; Reuse; Recycle; Recover; Redesign; Remanufacture	10R: Refuse; Rethink; Reduce; Reuse; Repair; Refurbish; Remanufacture; Repurpose; Recycle; Recover
Description	Early informal ideas of resource conservation (no formal "R" yet)	Formalized 3R concept globally for waste management	Introduced in Green Manufacturing, more production-focused	Formal academic structure for Circular Economy, ordered hierarchy
Trigger	Waste management (municipal solid waste, packaging)	Explosion of municipal waste volumes globally.	Need to shift from basic waste recycling to full green production systems (Jawahir & Bradley, 2016).	Maturation of Circular Economy research. Recognition that recycling alone is insufficient – upstream strategies (like Refuse and Rethink) are needed to prevent waste from happening in the first place (Potting et al., 2017).

Fig. 2

The 10R Framework (adapted from Potting et al., 2017)



As it goes down the hierarchy, mid-level strategies include Reuse (R3), Repair (R4), Refurbish (R5), Remanufacture (R6), and Repurpose (R7) to extend product lifespans, directly opposing the disposability inherent in linear systems. Finally, Recycle (R8) and Recover (R9) mitigate end-of-life

impacts by reclaiming materials or energy, rather than allowing them to be lost as waste. In this way, the 10R framework not only categorizes circular actions but also serves as a hierarchy model to highlight how each strategy systematically moves away from linear to a more circular model.

Recent empirical papers have applied the 10R Framework in construction settings. For instance, Wanaguru et al. (2022) developed a material-selection assessment framework for circular economy (CE) in Sri Lankan construction projects by ranking the relative importance of each R-strategy and proposing specific measures aligned with the 10R concepts. In addition, Senaratne et al. (2025) in Australia discussed the challenges and approaches to integrating the 10R Framework into modular buildings. For instance, through case studies and expert interviews, they illustrated how modular design facilitates "Rethink" and "Reuse" via disassembly. Zulkifli et al. (2024) in Malaysia also discussed the possible constraints in applying the 10R framework for construction and demolition projects, including poor marketing strategies as well as insufficient technological research and development. Nevertheless, the 10R Framework appears to be a versatile model that can be operationalized for different assessment objects–such as materials, components, or whole building systems–to indicate the extent to which they embed circular-economy strategies.

Green Building Rating System Structure & Selection

GBRS are organized platforms utilized to quantify and certify the green performance of buildings (Ade & Rehm, 2020). GBRS offers organized criteria to quantify the sustainability of a building in areas of energy use, material use, water use, and occupant comfort. As third-party verification tools, GBRS enables property developers, architects, and policymakers to signal and verify environmental stewardship beyond legally mandated code compliance (Ade & Rehm, 2020). Their fundamental mission is to foster better practice in planning, building, and other occupations of buildings against climate and resource concerns.

GBRS are structured through a hierarchical composition of indicators that collectively assess the sustainability performance of a building. As illustrated in the indicator system model (Fig. 3), this hierarchy is organized into multiple layers: scope, criteria, indicator categories, and terminal indicators, each serving a specific evaluative function within the assessment framework (Cai & Gou, 2023). This hierarchical system ensures that GBRS remains comprehensive, traceable, and adaptable. Each layer of the hierarchy supports decision-making by allowing assessments to be broken down into logical, measurable components, ultimately facilitating transparent certification processes and targeted improvements. It also enables data aggregation for visualization and reporting, which is critical for comparing sustainability performance across projects or over time.

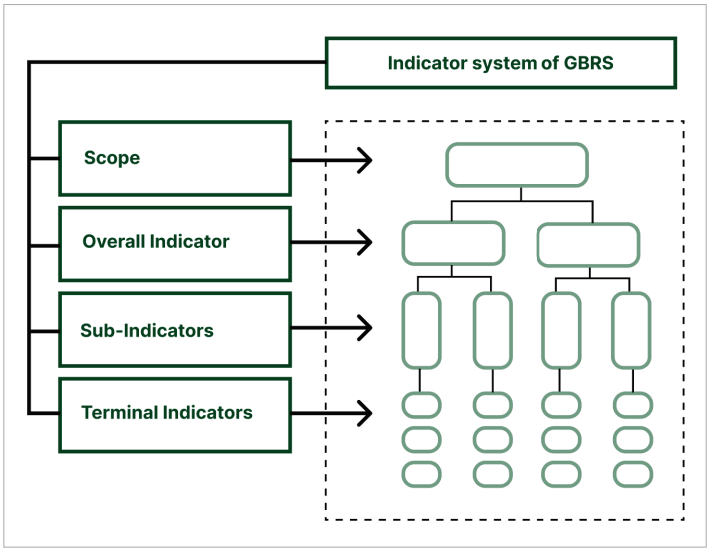


Fig. 3
Indicator System of GBRS (Cai & Gou, 2023)

This study selects four green building rating systems–LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Establishment Environmental Assessment Method), GREENSHIP, and BGH (*Bangunan Gedung Hijau*)–to capture both globally established and Indonesia-specific GBRS within the most common

scope of assessment, the new construction category. LEED, introduced in 1994 by the U.S. Green Building Council, and BREEAM, launched in 1990 by the Building Research Establishment in the UK, are among the most widely used international schemes and provide multi-tier certification frameworks for new construction alongside other building types. In contrast, GREENSHIP, developed in 2010 by the Green Building Council Indonesia, and BGH, issued in 2015 by the Ministry of Public Works and Public Housing as the national standard, reflect locally developed rating tools tailored to Indonesian conditions for new and existing buildings and area developments.

Secondary Data Collection of Green Building Rating System Indicators

Secondary data on GBRS indicators were collected through a systematic review of official documents published by the respective certification bodies. The most recent technical manuals and rating guidelines for BREEAM New Construction, LEED BD+C, GREENSHIP New Building, and BGH Tahap Perencanaan were obtained from the official websites of BRE, USGBC, GBCI, and the Ministry of Public Works and Public Housing (PUPR), respectively (Building Research Establishment, 2015; U.S. Green Building Council, 2024; Green Building Council Indonesia, 2016; Kementerian Pekerjaan Umum dan Perumahan Rakyat Republik Indonesia, 2015). Using only formal, published sources ensures that the indicator data are reliable, up to date, and consistent with how the schemes are implemented in practice.

The evolution of green building rating systems (GBRS) was driven by increasing concern over environmental degradation from conventional construction and the lack of credible mechanisms to verify sustainability claims (Ade & Rehm, 2020). Early systems emerged as third-party appraisal tools to enhance transparency and accountability. Building Research Establishment Environmental Assessment Method (BREEAM), developed by the Building Research Establishment in 1990, was the first formal GBRS, initially created in response to developer demand for demonstrating environmental performance. Leadership in Energy and Environmental Design (LEED), introduced by the U.S. Green Building Council in 1998, expanded this approach through a market-oriented, widely applicable framework. Subsequent systems adapted these models to local contexts. However, their developer-led and design-oriented origins have limited their transformative potential, as many GBRS prioritise predicted over actual performance and insufficiently address lifecycle circularity and long-term sustainability outcomes (Ade & Rehm, 2020).

For each system, all indicators and sub-indicators relevant to the design and construction stages under the "New Construction" category were extracted, including their titles, intents, descriptive texts, and, where applicable, point weights. The "new construction" category mainly corresponds to the A1–A5 stages of the LCA framework, covering material production (A1–A3) and construction processes (A4–A5). Since BGH is still in the planning stage, this assessment is prospective and based on projected materials and construction methods. However, although early design decisions in this phase might also influence impacts in later stages (B1–C4), the presence of any R-related credits in the GBRS should not be interpreted as guaranteeing future recovery outcomes. A study by Atik et al. (2024) suggested that the planning stage of a building's life cycle is a crucial intervention point, it cannot ensure any end results in the further stages due to limitations such as immature and incomplete initial information and even a shift in stakeholder priorities that often override initial intentions.

The extracted indicator sets were compiled into a structured dataset in Microsoft Excel, with fields capturing scheme name, category, indicator code, indicator title, description, and credit value. This consolidated dataset provides a standardised benchmark for evaluating circularity based on the 10R framework and forms the empirical basis for the subsequent analysis and interpretation of circularity across the four GBRS.

In line with recommendations for transparent sampling and unit definition in content analysis (Neuendorf, 2017), the "universe" of coded units was restricted to performance-related indicators

and sub-indicators within the new construction (or equivalent) categories of each scheme. After excluding purely administrative or documentation-only items that did not specify environmental or resource outcomes, the final analysed dataset comprised 44 indicators for BREEAM New Construction, 39 for LEED BD+C, 34 for GREENSHIP New Building, and 33 for BGH *Tahap Perencanaan*. These counts define the denominator for the R-count and R-credit percentages reported in Section 3 and ensure that comparisons across schemes are based on a clearly delimited and internally consistent set of assessment items.

Analysis and Interpretation of Circularity in Green Building Rating System Indicators

The analysis first examines how circularity is conceptualised and operationalised within the 10R strategies (R0–R9), using the framework proposed by Potting et al. (2017). Each green building rating system is then analysed individually to identify how circular strategies are framed and encouraged. Finally, these individual findings are synthesised to identify broader patterns and key differences in circularity intent across BREEAM New Construction, LEED BD+C, BGH Tahap Perencanaan, and GREENSHIP New Building. Then, to interpret the circular economy intent embedded in GBRS indicators, a verb-based signal-word coding scheme was developed and applied across all four systems. For each indicator, the primary action verb (e.g. "reduce", "reuse", "avoid") was identified and coded according to (i) whether it expressed a direct (explicit) or indirect (implicit) prescription, and (ii) the associated R-strategy (R0–R9) in the 10R circularity framework. The full list of signal words and their corresponding R-strategies is presented in Table 2.

Table 2
Signal-word Dictionary

Signal word(s)	Explicit / Implicit	Associated R-strategy	Notes/example interpretation
Avoid / Refuse / Prohibit	Explicit	R0 (Refuse)	Forbids high-impact options (e.g., "Avoid development on greenfield land," "Prohibit high-GWP refrigerants").
Reject / Exclude / Disqualify	Explicit	R0 (Refuse)	Explicitly rules out options (e.g., "Reject materials with high embodied carbon," "Exclude toxic coatings").
Limit	Implicit	R0 (Refuse)	Restricts quantity or capacity without a full ban (e.g., "Limit parking area to reduce land consumption").
Discourage	Implicit	R0 (Refuse)	Signals that a practice is undesirable (e.g., "Discourage excessive parking provision," "Discourage use of inefficient systems").
Prevent	Implicit	R0 (Refuse)	Aims to stop harmful practices or substances (e.g., "Prevent the use of ozone-depleting substances").
Encourage / Support	Implicit	R1 (Rethink), R2 (Reduce)	Suggests behaviour or processes that lead to rethinking or reduction (e.g., "Encourage integrated design workshops," "Support occupant awareness campaigns").
Consider / Explore	Implicit	R1 (Rethink)	Prompts reevaluation of design options (e.g., "Consider life-cycle impacts when selecting materials," "Explore alternative low-carbon designs").
Optimize	Implicit	R1 (Rethink), R2 (Reduce)	Implies analytical improvement for efficiency (e.g., "Optimize envelope to reduce cooling loads," "Optimize system sizing").
Inform	Implicit	R1 (Rethink)	Uses information to shape decisions (e.g., "Inform product selection using environmental product declarations").

Signal word(s)	Explicit / Implicit	Associated R-strategy	Notes/example interpretation
Model / Simulate	Implicit	R1 (Rethink)	Uses simulation to rethink design choices (e.g., "Model thermal performance under future climate scenarios").
Plan / Specify	Implicit	R1 (Rethink)	Up-front design and specification decisions (e.g., "Plan maximum basement depth," "Specify sensor-controlled lighting").
Design / Allocate	Implicit	R1 (Rethink)	Layout or spatial decisions (e.g., "Design façade orientation by sun path," "Allocate a minimum share of green area").
Choose / Select	Implicit	R1 (Rethink)	Procurement rules (e.g., "Select responsibly sourced timber," "Choose local materials within a defined radius").
Integrate / Embed	Implicit	R1 (Rethink)	Embed systems and circularity into the design (e.g., "Integrate building management systems and sub-metering," "Embed on-site wastewater treatment").
Operate / Manage	Implicit	R1 (Rethink)	Ongoing management aligned with circular principles (e.g., "Manage urban green networks," "Maintain 3R-based waste systems").
Require / Mandate	Implicit	R1 (Rethink), R9 (Recover)	Makes circular features compulsory (e.g., "Require high-efficiency fixtures," "Mandate rainwater detention or recovery systems").
Reduce / Minimize / Lower	Explicit	R2 (Reduce)	Explicit command to cut resource use or impact (e.g., "Reduce potable water demand," "Lower operational energy use").
Promote	Implicit	R2 (Reduce)	Motivates choices that reduce impact (e.g., "Promote active transportation," "Promote low-energy appliances").
Reuse / Salvage / Repurpose	Explicit	R3 (Reuse)	Calls for using existing elements or materials (e.g., "Reuse structural framing," "Salvage interior finishes").
Enable	Implicit	R3 (Reuse), R5 (Refurbish), R9 (Recover)	Provides capacity for circular options (e.g., "Enable future layout reconfiguration," "Enable greywater reuse systems").
Repair / Maintain	Explicit	R4 (Repair)	Commands maintenance or repair to prolong service life (e.g., "Maintain HVAC systems to maximize lifespan").
Remediate / Restore	Explicit	R4 (Repair)	Fixes existing damage (e.g., "Remediate contaminated soil before construction," "Restore degraded landscape").
Refurbish / Upgrade	Explicit	R5 (Refurbish)	Instructs upgrading or refurbishing instead of replacing (e.g., "Refurbish façade systems to extend lifespan").
Recycle / Divert	Explicit	R8 (Recycle)	Requires waste to be diverted to recycling streams (e.g., "Recycle 75% of construction and demolition waste").
Facilitate	Implicit	R8 (Recycle)	Enables recycling or circular flows (e.g., "Facilitate on-site waste sorting and recycling").
Provide space for	Implicit	R8 (Recycle)	Reserves physical space for circular practices (e.g., "Provide space for separated waste storage and recycling").
Recover	Explicit	R9 (Recover)	Calls for recovering resources (e.g. "Recover waste heat").

Explicit signal words were defined as verbs that explicitly command or prohibit an action. Examples include "Reduce/Minimize/Lower, Reuse/Salvage, Refurbish, Recycle/Divert, Recover, Avoid/Reject/Exclude". These were mapped to the R-strategy that they most immediately operationalise: R2 (Reduce) for instructions to reduce resource, energy or land use; R3 (Reuse) and R5 (Refurbish) where continued use or upgrading of existing components is required; R4 (Repair) where remedial action is mandated; R8 (Recycle) and R9 (Recover) where material, water or energy recovery is required; and R0 (Refuse) where high-impact options are explicitly avoided, rejected or excluded.

Implicit signal words were defined as verbs that encourage, enable, or condition particular design choices without explicitly commanding them. In BREEAM and LEED, these include "Encourage, Support, Facilitate, Consider, Enable, Promote, Optimize, Model, Limit". Such terms were interpreted as signaling higher-order strategies, primarily R1 (Rethink), where they require up-front design integration, scenario analysis, or procurement rules. Depending on the object of the verb, they were additionally linked to R0 (Refuse), R2 (Reduce), R5 (Refurbish), R8 (Recycle), or R9 (Recover). For example, "provide space for waste segregation bins" was coded as R8 (Recycle), "enable greywater reuse systems" as R9 (Recover), and "discourage excessive parking" as R0 (Refuse). Where an indicator could plausibly activate more than one strategy, multiple R-codes were assigned.

The terminology-based coding procedure followed qualitative content analysis (Krippendorff, 2019; Neuendorf, 2017). A detailed coding protocol derived from the 10R framework and the signal-word dictionary in Table 2 was first piloted on a subset of indicators drawn from all four schemes. After this calibration, both coders independently coded the full indicator dataset, assigning one or more R-strategies (R0–R9) to each indicator were justified by the indicator text. Intercoder reliability is a central concern in content analysis, particularly to demonstrate that coding decisions are not idiosyncratic (Krippendorff, 2019; Neuendorf, 2017). In this exploratory study, coder agreement was strengthened through iterative discussion: all initial coding discrepancies were identified, jointly reviewed, and resolved by consensus. This procedure ensured that the final coding reflects a shared interpretation of how each indicator relates to the 10R framework, while the absence of a quantified reliability coefficient remains a methodological limitation that future research could address more rigorously (Krippendorff, 2019; Neuendorf, 2017).

Based on this reconciled coding, the analysis generates the total credit value associated with each R-strategy where point weights are available (R-credit). These metrics are expressed as percentages of the total indicators and total available points within each system. When overlapping, i.e. two or more R-strategies being allocated in the same indicator, the available points were fractioned accordingly to avoid redundancy in totalling. This allows the study to compare not only how frequently each R-strategy appears but also how strongly it is incentivized in the scoring structures. The resulting R-profiles are then compared across BREEAM, LEED, GREENSHIP, and BGH to reveal similarities or differences in how circularity is embedded in their indicators and rating logic. Additionally, while the 10R framework is often discussed in relation to both technical and biological material loops, the present study applied it as an action-based classification of GBRS credits. As such, the mapping focused on the circular strategy expressed in each indicator, rather than on explicitly distinguishing whether the intended pathway belonged to a technical or biological loop.

To further examine whether the relative emphasis on 10R strategies differed across the four GBRS, a Kruskal–Wallis test was conducted using the percentage distribution of credits assigned to each R-strategy. Percentage values were used to normalize differences in total available credits across the rating systems. The results of the test were presented using the chi-squared statistic (x^2) and p-value to determine whether the observed variations across GBRS were statistically significant.

Expert Validation

Expert validation was conducted to strengthen the credibility of the signal-word mapping of 10R strategies across GBRS and to reduce subjectivity in the lexicon-based and interpretive coding process. Expert judgment is widely used in content validation to assess whether categories and their assignments are relevant, conceptually appropriate, and sufficiently clear for the construct under study (Almanasreh et al., 2019). In this research, the external review served as a targeted credibility check to confirm that the assigned R-strategies adequately reflected the intent of each GBRS credit, including credits with overlapping strategies or those classified outside the 10R framework. However, the methodological literature generally recommends multi-expert panels for formal content validation; yet this study uses only one external expert to support coding credibility, rather than full panel-based content validation.

The selected external expert has over a decade of experience in green building consultancy, technical advisory, and sustainable development. Their background includes doctoral and master's degree in environmental science, professional experience as an EDGE Technical Specialist for the International Finance Corporation, involvement in certification and capacity-building for public and private stakeholders, and work on rating development with the Green Building Council Indonesia. These qualifications make the expert credible and well-suited to evaluate the consistency and practical relevance of the 10R mapping across the assessed GBRS.

Results

Signal-word mapping

Table 3 shows the mapping of R strategies across the four GBRS. The normalized heatmap was calculated using only scored indicators, excluding "prerequisite" indicators because they do not have equivalent numeric credit values and are not uniformly present across all GBRS. However, to ensure that this study does not ignore the administrative planning, the relationship of prerequisite indicators on LEED and GREENSHIP to the 10R strategies is reported separately as a side analysis rather than incorporated into the scored distribution. Across all GBRS, over 10% of credits are not-related to any R strategy, with 25.76% found in BREEAM. This category mainly comprised indicators that fell into the category of indoor air quality and human comfort, as they were considered to not influence material loops or energy/resource flow.

In the four GBRS, R1 (Rethink) and R2 (Reduce) dominate the overall credit, followed by R0, R8, R9, R4, R3, and R5. Interestingly, R6 and R7 were not found in any GBRS credits. R1 accounts for 18.27% (GREENSHIP) to 38.84% (BGH) of the total credit of all R-mapped indicators. R2 (Reduce) appears in 23.61 %–59.62 % of indicators, with the most being found in GREENSHIP, followed by BREEAM, BGH, and then LEED. These strategies are found in most indicators regarding materials, energy, water, indicated by signal-words such as "reduce," "minimize," and "lower" (R2) and "encourage," "support," and "consider" (R1).

Furthermore, R0 (Refuse) was found in all GBRS, although weighing less, accounting for 1.36%–15% of the whole credit. These credits demand "no build" on greenfields, refusal of high-ODP refrigerants, or total bans of polluting activities. R8 (Recycle) and R9 (Recover) were also found in all GBRS, although together account for no more than 5.20% of total credit. These loops reward on-site or on-board waste-sorting, recycled-content materials, bilge-water collection, or exhaust-heat recuperation, but their percentage is low in comparison to R1/R2.

R3 (Reuse), R4 (Repair) and R5 (Refurbish) were not found in all GBRS. R4 was found in only three GBRS, excluding BREEAM, with 1.82% credits at most. R3 was only found in LEED (4.44%) and BGH (0.20%), with a very low percentage. Whereas R5 was only found in BREEAM, accounting for 6.67% of all credits. In contrast, R6 (Remanufacture) and R7 (Repurpose) are not mentioned at all, meaning midstream circular activities such as upgrading major subassemblies, remanufacturing components, or repurposing building or ship components for new uses, are effectively uncredited.

Table 3

Heatmap of Dominant R-Level in the four GRBS

R-Category	BREEAM	LEED	BGH	GREENSHIP
	% from total credit	% from total credit	% from total credit	% from total credit
Not-related	25.76	18.33	11.52	10.58
R0	1.36	15.00	9.90	3.85
R1	22.26	36.25	38.84	18.27
R2	37.18	23.61	30.56	59.62
R3	0.00	4.44	0.20	0.00
R4	0.00	1.25	1.82	0.96
R5	6.67	0.00	0.00	0.00
R6	0.00	0.00	0.00	0.00
R7	0.00	0.00	0.00	0.00
R8	5.08	0.69	5.20	3.37
R9	1.69	0.42	1.97	3.37
Total	100.00	100.00	100.00	100.00

Min. Value (0)
Based on credit % per GBRS

Max. Value
Based on credit % per GBRS

Overall, a consistent pattern emerges across BREEAM New Construction, LEED BD+C, BGH *Tahap Perencanaan*, and GREENSHIP New Building. First, the GBRS tend to prioritise quantifiable reductions (R2: Reduce) and up-front systemic thinking (R1: Rethink) as the main vehicles for operationalising circularity. Deeper reuse, repair, and recovery loops (R3, R4, R5, R8, R9) remain marginal in both frequency and scoring weight, while remanufacturing and repurposing strategies (R6, R7) are absent.

Table 4

Mapping of 10R strategies on Prerequisite indicators in LEED and GREENSHIP

GBRS	Prerequisite Indicator	Related R-strategy
LEED	Outdoor Water Use Reduction	R2
	Indoor Water Use Reduction	R2
	Building-Level Water Metering	R1, R2
	Fundamental Commissioning and Verification	Not-related
	Minimum Energy Performance	R1, R2
	Building-Level Energy Metering	R1, R2
	Storage and Collection of Recyclables (Prerequisite)	R2
	Minimum IAQ Performance (Prerequisite)	Not-related
	Environmental Tobacco Smoke Control (Prerequisite)	Not-related
GREENSHIP	ASD P: Basic Green Area	Not-related
	EEC P1: Electrical Sub-metering	R1
	EEC P2: OTTV Calculation	R1
	WAC P1: Water metering	R1
	WAC P2: Water use calculation	R1
	MRC P: Fundamental Refrigerant	R1
	IHC P: Outdoor air Introduction	Not-related
	BEM P: Basic waste management	R1, R8

Statistically, the results of the Kruskal–Wallis test across GBRS indicated a very small chi-squared value ($x^2 = 0.178$) and a high p-value ($p = 0.981$). These results show that no statistically significant differences were detected among the GBRS in their overall 10R emphasis. This finding supports the interpretation that the four GBRS exhibit a broadly similar pattern of circularity orientation.

In terms of prerequisite indicators in LEED and GREENSHIP, Table 4 presents how each indicator is mapped against the 10R strategies. In LEED, 3 out of 9 prerequisites are not directly related to any 10R strategy as they are not considered influential to circular loops. As for the other prerequisites, 3 out of 8 are related to only R2, whereas the remaining 3 overlaps between R1 and R2 strategies. Similarly, 2 out of 8 credits in GREENSHIP also were considered not-related to circularity. R1 significantly dominates the prerequisites in this GBRS, being found in all the remaining prerequisites, although one overlaps with R8. Overall, these prerequisite mappings further corroborate the main heatmap results by showing that, even outside the scored distribution, circularity-related administrative and procedural requirements are still concentrated primarily in R1 and R2.

Framing of "Circularity" across GBRSs

Each GBRS conveys circular economy principles through a specific combination of terminology and point weighting. Analysing the verbs associated with indicators reveals how circular strategies are implemented explicitly (through direct R-verbs) and implicitly (through enabling or indirect verbs) (Table 5).

In BREEAM New Construction, "Reduce" (R2) dominates, with 37.18% of the available credits directly tied to reductions in energy, water, and material use, with verbs such as "reduce", "minimize", and "lower" appearing frequently. A secondary emphasis on "Rethink" (R1) accounts for 22.26% of credits, typically through credits requiring life-cycle costing, integrated project planning, and commissioning, often framed with verbs such as "encourage", "support", and "consider". For most indicators, R1 and R2 were found to be overlapping. Although minimal, there were also visible incentives for "Recycle" (R8), "Recover" (R9), and "Refuse" (R0); for example, by discouraging development on greenfield sites, rejecting the use of high-GWP refrigerants, and requiring a diversion of construction and demolition waste from landfill. This GBRS also stood out as the only one with R5 strategies in its indicators, accounting for 6.67% of credits, and was found in indicators discussing material durability and functional adaptability.

In LEED BD+C (v4/v4.1), "Reduce" (R2) and "Rethink" (R1) together capture nearly 60% of total credit points, with most indicators overlapping between the two strategies. Explicit language such as "reduce", "minimize", and "avoid" (signalling R0) is complemented by enabling verbs like "consider", "encourage", "optimize", and "inform", which signal R1. LEED also devotes 15% of its points to "Refuse" (R0), for instance, by restricting development on sensitive lands or prohibiting high-VOC and other unsustainable materials. While "Reuse" (R3), "Repair" (R4), "Recycle" (R8), and "Recover" (R9) appear in credits on adaptive reuse, construction and demolition waste management, and water recovery, each of these downstream or end-of-life loops individually accounts for less than 5 % of the total points, indicating a supportive but secondary role.

In BGH *Tahap Perencanaan*, the framing is even more strongly skewed toward "Rethink" (R1) and "Reduce" (R2), accounting for nearly 70% of credits attributed combined. "Rethink" (R1) accounts for 38.84% of the available points, linked to decisions such as optimising site orientation, specifying high-albedo or low-emissivity materials, providing extensive canopy cover, and integrating parking, electric-vehicle facilities, non-motorised transport, and green open space–often guided by verbs like "plan", "design", "choose", and "integrate". R2 strategies were evident in terms that suggested outright "disqualification", "limits", or "avoidance" of features considered

incompatible with green-building objectives, underscoring a relatively strong stance against inherently harmful choices. Nearly 20% of points were awarded for "Refuse" (R0), "Reuse" (R3), "Repair" (R4), "Recycle" (R8), and "Recover" (R9), covering runoff control, water-efficient fixtures, greywater use, salvaged materials, soil remediation, and basic construction and demolition waste separation.

Table 5
Framing of Circularity in each GBRS

GBRS	Explicit	Implicit
BREEAM New Construction	_ reduce, minimize, lower → R2 (Reduce) _ reuse → R3 (Reuse) _ refurbish → R5 (Refurbish) _ recycle → R8 (Recycle) _ recover → R9 (Recover) _ avoid, reject, exclude → R0 (Refuse)	_ encourage, support, consider, promote, optimize, inform → R1 (Rethink) (occasionally R2) _ plan, design, integrate, monitor → R1 (Rethink) (occasionally R2)
LEED BD + C (v4/v4.1)	_ reduce, minimize, lower → R2 (Reduce) _ reuse, salvage → R3 (Reuse) _ recycle, divert → R8 (Recycle) _ recover → R9 (Recover) _ repair, maintain → R4 (Remediative Repair) _ avoid, refuse, prohibit → R0 (Refuse)	_ encourage, support → R1 (Rethink) / R2 (Reduce) _ consider, explore → R1 (Rethink) _ promote, facilitate → R2 (Reduce) / R8 (Recycle) _ optimize, inform → R1 (Rethink) / R2 (Reduce) _ enable, provide → R3 (Reuse) / R9 (Recover) _ plan, design, integrate → R1 (Rethink) / R2 (Reduce)
BGH *Tahap Perencanaan*	_ reduce, minimize → R2 (Reduce) _ reuse → R3 (Reuse) _ recycle → R8 (Recycle) _ remediative, repair→ R4 (Repair) _ avoid, refuse, prevent → R0 (Refuse)	_ plan, design, choose, integrate → R1 (Rethink) _ manage, preserve→ R1 (Rethink) _ disqualification, limit, avoid → R0 (Refuse) _ recover → R9 (Recover)
GREENSHIP New Building (v1.2)	_ reduce, minimize, optimize → R2 (Reduce) _ reuse, salvage → R3 (Reuse) _ recycle → R8 (Recycle) _ recover → R9 (Recover) _ repair, maintain → R4 (Remediative Repair) _ avoid, refuse → R0 (Refuse)	_ plan, design, monitor, embed → R1 (Rethink) _ integrate, coordinate, evaluate, inform → R1 (Rethink) _ optimize → R2 (Reduce) / R1 (Rethink) _ provide, enable → R3 (Reuse) / R5 (Refurbish) / R8 (Recycle) / R9 (Recover)

GREENSHIP New Building significantly highlights "Reduce" (R2), allocating nearly 60% of its 88 total points to reductions in operational energy, water use, and waste generation. Credit language frequently uses "reduce", "minimize", and "optimize" to direct choices in envelope design, HVAC efficiency, lighting, metering, and operational practices. "Rethink" (R1) is also prominent with 18.27% of credits, as suggested by indicators involving integrated planning of site layout and resource flows, with verbs such as "plan", "design", "monitor", and "embed". Smaller point pools–together nearly 12 %–reward "Refuse" (R0) through limitations or bans on high-impact design options, "Recycle" (R8) through requirements for waste sorting and material recycling, "Recover" (R9) via water reuse and energy recovery, "Reuse" (R3) through salvaged materials, and "Repair" (R4) via maintenance and performance-preservation measures.

Across all four systems, common framing patterns emerge. Explicit R-verbs such as “reduce”, “avoid”, “reuse”, “recycle”, “recover”, and “repair” map clearly onto R0, R2, R3, R4, R8, and R9, representing direct circular strategies. In contrast, enabling verbs such as “plan”, “design”, “select”, “integrate”, “encourage”, “consider”, “promote”, “optimize”, “embed”, “monitor”, “provide”, and their Indonesian equivalents consistently mark indirect incentives associated with R1 (and occasionally R2). The distribution of points reinforces these linguistic patterns: where “reduce/minimize” language is most prevalent, R2 secures the largest share of credit weight; followed by R1 indicated by words such as “plan”, “design”, and “integrate”.

Additionally, the mapped indicators across all GBRS were found to be more concerned with material procurement than with material circulation after use. Credits frequently refer to eco-labeling, responsible sourcing, or prefabricated systems, which emphasize selecting environmentally preferable materials at the point of specification or purchase. This further reflects the GBRS’s tendency toward an upstream circularity logic, aligning closely with R1 and R2 strategies, yet not explicitly distinguishing between the technical and biological loops of the resources.

Discussion

In a comparative analysis of the GBRS, it was found that across all systems, at least 10% of credits were not associated with any R strategy, as they were considered unrelated to material loops or energy/resource flows. Notably, BREEAM had the highest percentage, with 25.76% of its credits falling into this non-related category. This indicates a structural misalignment between existing GBRS frameworks and circular economy principles, where a substantial share of assessment criteria does not engage with material loops or resource flows, thereby limiting their effectiveness in driving genuinely circular outcomes.

This percentage suggests that all of these frameworks encourage early, coordinated choices–site orientation, envelope design, life-cycle analysis, integrated metering, or voyage planning–that are based on circular principles before construction or operation. However, this also implies that circularity is predominantly addressed at the design stage, with comparatively limited emphasis on downstream strategies such as reuse, remanufacturing, or recovery during the building’s operational and end-of-life phases.

Beyond the dominance of R1 and R2, the lower representation of R3, R4, R5, R8, and R9 (0.20%–6.67%) suggests that the current GBRS provided only limited recognition for strategies that extend the service life of materials and components through reuse, repair, refurbishment, recycling, or recovery. This aligns with the broader observation that most GBRS prioritise design-stage interventions over operational and end-of-life strategies, resulting in limited integration of circular practices that sustain material value across the building lifecycle.

The notable absence of R6 (Remanufacture) and R7 (Repurpose) across all four GBRS further indicates that more transformative midstream circular activities have not yet been meaningfully translated into mainstream rating criteria. This suggests that current GBRS frameworks remain limited in capturing transformative circular practices, particularly those that reconfigure materials and components into new value streams, thereby constraining their ability to support deeper, system-level circular transitions.

The four GBRS showed no statistically significant differences in their overall 10R distributions ($x^2 = 0.178$, p-value = 0.981). This suggests that, despite differences in structure, terminology, and regional context, all four GBRS share a similar orientation, dominated by the same circularity strategies. This aligns with the notion that contemporary GBRS have evolved from shared foundational models and principles, resulting in convergent frameworks that prioritise similar circularity approaches across different contexts.

The linguistic analysis further supports the heatmap results by showing that circularity in all four GBRS is expressed through both explicitly-stated R-verbs and implicitly broader supporting terms.

This suggests that the strong presence of R1 and R2 is not only visible in the credit distribution, but also reflected in the way circularity is described across the assessed systems. This further corroborates the finding that circularity within GBRS is predominantly framed through upstream, design-oriented strategies, both structurally in credit allocation and discursively in the language used to define sustainability.

LEED and BGH show a higher use of R1-related terms, including "plan", "design", "consider", "encourage", and "integrate". This suggests that, in these systems, circularity is framed more as an early-stage design and planning approach. Conversely, BREEAM and GREENSHIP showed a stronger share of R2 through the frequent use of terms such as "reduce", "minimize", "lower", and "optimize" in credits related to energy, water, and material efficiency. This shows that these systems mainly translate circularity into measurable reductions in resource use and overall environmental impact. This aligns with the broader understanding that circular economy principles in the built environment are often operationalised through efficiency-driven strategies, focusing on minimising resource input and environmental impact rather than maintaining material value across lifecycles.

The linguistic results also explain why the downstream strategies remain weak in the heatmap. The low presence of R3, R4, R5, R8, and R9, also the absence of R6 and R7 is not only due to lower credit weighting, but also because these strategies appear less often, if any, in the main wording of GBRS indicators, reinforcing the finding that current frameworks still focus more on prevention and efficiency than on deeper restorative loops. This aligns with the broader observation that GBRS predominantly frame circularity through upstream, efficiency-driven strategies, while downstream processes that sustain material value across lifecycles remain underrepresented both structurally and discursively.

Conclusions

This study interprets circularity in various GBRS indicators in accordance with the 10R framework. The analyses involved mapping every credit in BREEAM New Construction, LEED BD+C, BGH *Tahap Perencanaan*, and GREENSHIP New Building to the 10R categories (R0–R9), as the most comprehensive circular metric (Potting et al., 2017), and analyzing the signal words. As a result, this study discovered that at least 10% of credits in all GBRS were not attributed to any R strategies as they were unrelated to resource loops, suggesting that a notable portion of GBRS criteria still addresses broader sustainability concerns without directly contributing to circular material or resource flows. In terms of circularity strategies, R1 (Rethink) and R2 (Reduce) dominate all of the four GBRS. BREEAM and GREENSHIP distribute most of their credits to R2 (measurable reductions in energy, water, or materials), whereas LEED and BGH *Tahap Perencanaan* leaned more in the direction of R1 through encouragement of integrated planning and sustainable design considerations. These indicate that circularity is primarily operationalized in current GBRS through early-stage decision-making and efficiency-oriented interventions, rather than through lifecycle-based material circulation.

Although R0 (Refuse) appears everywhere, it carries very little weight. All four systems have some "refuse" credits–greenfield exclusion, no-HFC refrigerants, and banning of damaging practices–valued at up to 15% of all points, suggesting that to "avoid harm" is an essential circular intervention. In contrast, downstream loops (R3–R9) are significantly less pronounced. "Reuse" (R3) , "Repair" (R4), "Recycle" (R8), and "Recover" (R9) account for no more than 6% of the points for diverting building waste, grey-water reuse, or bilge-water capture. Notably, no system incentivizes R6 (Remanufacture) or R7 (Repurpose) in any of its indicators or credits. These indicate that more restorative and transformative circular strategies remain weakly embedded in existing GBRS, limiting their capacity to support full lifecycle circularity beyond prevention and resource efficiency.

Statistically, the Kruskal-Wallis test results also indicate that there was no significant difference in terms of 10R implementation across the GBRS. For future development, it is also suggested to perform linguistic shifts to strengthen the circularity weight. Hence, the study shows that all four GBRS treat circularity primarily as either (1) R1: up-front, integrative design thinking or (2) R2: concrete, verifiable resource cuts. Circularity is defined as an early intervention rather than downstream loops. Terminology-wise, direct R-verbs drive the higher-point allocations, whereas indirect language signals early design interventions.

This study has several limitations to be addressed in future research. First, the comparison was limited to only four GBRS: BREEAM, LEED, GREENSHIP, and BGH. Exploring a wider range of international and national GBRS could yield richer comparative insights. Second, the analysis focused primarily on new building/construction (LEED, GREENSHIP, and BREEAM) and the planning phase (BGH). Future studies could expand the scope to investigate existing building retrofits or other project phases, such as the construction or operational stages, to provide a more comprehensive understanding of the standards' applicability.

Additionally, this research offers several practical implications based on the findings. For policymakers, the analysis can serve as a reference for refining national regulations and incentives to promote sustainable construction, particularly by learning from the strengths of international standards. Designers and developers can use the identified similarities and differences to strategically select the most appropriate GBRS for their projects, ensuring effective integration of sustainability principles from the outset.

Acknowledgement

The authors would like to thank Dr. Yanu Aryani, S.Si., M.Si., an external expert, for her support in expert validation through reviewing our signal-word and mapping results for increased credibility. This publication was supported by the Program of Article Processing Charge (APC) Journal Publication Assistance for 2026 from the Research, Innovation, and Community Service Division of the Faculty of Engineering, University of Indonesia (Grant Number NKB-1539/UN2.F4.D/PPM/00.04/2026)"

Use of Artificial Intelligence Tools

During the preparation of this article, the authors used ChatGPT by OpenAI to support language editing, improve readability, and assist with the preliminary organization of ideas and references during manuscript preparation. The AI tool was not used to generate original data, conduct data analysis, or make final interpretations. The authors independently reviewed, edited, and verified the content and assumed full responsibility for the accuracy, originality, and integrity of the work.

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