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Green Building Rating Systems: A Critical Comparison between LOTUS, LEED, and Green Mark

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Abstract

Despite being established in Vietnam for over a decade, LOTUS has not achieved the same popularity as other international green building rating systems (GBRS), such as LEED and Singapore's Green Mark (GM). Consequently, concerns about its effectiveness persist. This study employed a systematic literature review to compare and analyse the effectiveness of LOTUS against LEED and GM rating systems. The findings revealed that LEED was the most widely adopted GBRS in Vietnam. While the primary criteria identified across all three systems were energy, water, materials, and indoor environment, the critical aspect of sustainability was environmental. Although GM placed a greater emphasis on sustainability and climate-responsive design, LEED and LOTUS prioritised site location. These results suggest that the late introduction and complexities surrounding the initial versions of LOTUS significantly contributed to its limited popularity in Vietnam. To enhance its effectiveness, this study recommends that the Vietnam Green Building Council (VGBC) increase its engagement with green building researchers and construction stakeholders both within and outside Vietnam, with the aim of simplifying its approach. A more user-friendly and streamlined version of LOTUS will likely encourage adoption by Vietnamese construction practitioners, thereby raising awareness of green building practices in Vietnam.

Keywords: Green Building Rating Systems; Sustainable Development; Vietnam; LOTUS; LEED; Green Mark

1 Introduction

Buildings contribute significantly to social wellbeing, economic development, and the protection of the environment (Cai & Gou, 2023; Olawumi & Chan, 2020). However, buildings also negatively influence human health and the environment through the consumption of a huge amount of energy and natural resources during their lifetime (Amanowicz et al., 2023; Omer & Noguchi, 2020). Over the past two decades, green building rating systems (GBRSs) have been used as an effective method to promote sustainable development (SD) as a comprehensive sustainability measurement for the whole life-cycle of buildings (Alawneh et al., 2019; Ansah et al., 2019; Song et al., 2023). Accordingly, Building Research Establishment Environmental Assessment Method (BREEAM), developed by Building Research Establishment (BRE) in the United Kingdom (UK), was the first sustainability assessment method (Alyami & Rezgui, 2012; Bahale & Schuetze, 2023). However, despite the novel establishment of BREEAM, the United States Green Building Council (USGBC) released LEED, which has gained the most popularity among GB certification systems worldwide based on the number of countries that have adopted it and the number of projects certified (Cascone, 2023; Doan et al., 2017). Besides, Singapore's Building and Construction Authority (BCA) launched the Green Mark (GM) in 2005, the first GB rating system in Southeast Asia and the first rating tool for tropical climates (Lai et al., 2023; Ting, 2012).

Vietnam is a developing country in South East Asia faced with issues relating to a lack of housing supply, high energy and natural resources consumption, and environmental pollution generated from the consequences of rapid economic development, urbanisation, and industrialisation (Cai & Le, 2023; Pham et al., 2019). Vietnam is also among the five nations most vulnerable to rising sea levels and changing climate due to its "long coastline, and low lying and densely populated delta regions" (Duijndam et al., 2023; Nguyen & Gray, 2016). As construction and other related industries contributed 34.49% of Vietnam's GDP in 2019 (General Statistic Office of Vietnam, 2019), the Vietnamese government considers sustainable construction through GB as a potential solution to address these identified problems (Pham et al., 2019).

Over the last decade, the GB concept has gained popularity and recognition in Vietnam due to its potential social, economic, and environmental benefits (Pham et al., 2020; Xuan Anh et al., 2023). Accordingly, LEED was the first GBRS adopted in Vietnam (Nguyen et al., 2019), with the advantage of its history, flexibility, and popularity. This was followed by GM, the second GBRS adopted in Vietnam through the projects developed by Singaporean investors due to the similarity in geographic and climatic conditions (Keppel Land Vietnam, 2009). In response to the global "going green" effort, the Vietnam Green Building Council (VGBC) was established in 2007 to promote sustainable construction in Vietnam (Vietnam Green Building Council, 2020b) and developed LOTUS as the GB rating tool specifically for Vietnam's building conditions (Vietnam Green Building Council, 2020c). Nevertheless, as of December 2020, LEED was identified as the most popular GBRS in Vietnam, with 238 registered and 93 certified projects (Vietnam Green Building Council, 2020e). This was followed by LOTUS with 34 certified projects from 71 registered projects (Vietnam Green Building Council, 2020e).

Although LOTUS was established in Vietnam over a decade ago and has gained significant attention from construction professionals, stakeholders and the government, its adoption process by Vietnamese construction professionals is still slow and in its initial stage (Nguyen et al., 2017). Moreover, LOTUS has less recognition in Vietnam than LEED. Despite earlier claims about its higher applicability and lower cost, it does not have a significant advantage over GM in the housing market (Nguyen et al., 2017). Some researchers have pointed out reasons for the less recognition of LOTUS in Vietnam to include the lack of relevant experience of users and the limitation of technical support availability (Pham et al., 2019), the lack of support and incentives from the government (Nguyen et al., 2019), and legislative barriers (Nguyen et al., 2017). However, the suitability of LOTUS in comparison with LEED and GM in terms of their categories, credits, criteria, and update process their abilities to evaluate SD in the Vietnamese context, has not been examined. More specifically, the following questions about these GBRSs need to be addressed:

1. How has the interest and research in LOTUS, LEED, and GM developed?
2. What are the similarities, differences, strengths, and weaknesses of the three GB rating tools?
3. How does each rating system balance the three pillars of SD?

4. What can be done to LOTUS to enhance its recognition and adoption in Vietnam?

This research aims to develop a systematic review of three primary GBRSs in Vietnam. They are LOTUS, the localised rating system; LEED, the most popular rating system worldwide; and GM, the first rating system in Southeast Asia and for the tropical climate. The result of this research would be valuable for Vietnam's GB council to promote the recognition and adoption of LOTUS in Vietnam. Also, this research can assist project developers in Vietnam in choosing the GB scheme that would best suit the characteristics of their future projects. Along with the limited numbers of research on the GB concept in Vietnam, this study is a considerable contribution to the existing body of knowledge to promote awareness of the GB concept in Vietnam. Further study is anticipated to explore the economic aspect of GB by analysing the initial cost and the whole life-cycle cost of GB-certified projects in Vietnam.

2 Literature Review

Although several researchers have examined the GB concept in Vietnam, a focus on the development of GBRSs adopted in Vietnam and their criteria have not been examined. For example, Nguyen and Gray (2016) highlighted development-related challenges such as "increasing demand for buildings, including growing population and over-urbanisation, predicted insecurity of energy supply, and environmental detriment and negative impacts of climate change". Accordingly, the Vietnamese government considered embracing the GB strategy as a solution to such development-related challenges and are even taking more decisive actions to promote GB adoption, such as ratifying regulations or offering incentives (Nguyen & Gray, 2016). However, legislative barriers, amongst other social-economic barriers, have been identified by Nguyen et al. (2017) as the most significant obstacle to GB's popularity in Vietnam. Also, Nguyen et al. (2019) investigated how the GB practice can be promoted in Vietnam and highlighted financial and economic incentives as the primary motivators for GB adoption. However, these studies did not examine the suitability of the GB rating systems to Vietnam's conditions in terms of categories and criteria.

42 LEED 2009 New Construction projects certified in Vietnam were examined to investigate the credit differences between LEED certificate levels by Pham et al. (2019).

Nevertheless, the credit differences between LEED and LOTUS rating systems were not analysed. Also, Pham et al. (2019) investigated the challenges that general contractors face when implementing LEED V4 BD+C (Building Design and Construction) in Vietnam. They found that Vietnamese general contractors find it hard to implement LEED credits such as Construction Activity Pollution Prevention, Fundamental Commissioning, Construction and Demolition Waste Management, and Construction Indoor Air Quality Management. Nine GBRSs, including LOTUS from Vietnam, were examined by Luangcharoenrat and Intrachooto (2019), but only one specific version of each system was examined. In other words, the research did not consider the progress update of the systems. Moreover, the paper focused on GB development in Malaysia instead of Vietnam. Vietnamese general contractors also lack experience in choosing and purchasing LEED materials (Pham et al., 2019). Again, these past studies only covered the challenges of LEED project implementation, not the LOTUS and GM projects.

Several international studies that have compared GBRSs excluded LOTUS. For example, Nguyen and Altan (2011) compared various aspects of five prominent GBRSs (BREEAM, LEED, CASBEE (Japanese Comprehensive Assessment System for Built Environment Efficiency), GREEN STAR, and HK-BEAM). They found the BREEAM and LEED to be the finest GBRSs worldwide. Another study compared two tropical GBRSs systems (i.e., Malaysia's GB Index and Singapore's GM). It concluded that "the rating tools developed for temperate and tropical countries are not directly comparable" (Ting, 2012). Despite the climate similarity, there are still differences between GB Index and GM rating systems because of the differences in other aspects, such as state of development, existing resources, cultural relevance, and social needs. Krajangsri and Pongpeng (2018) compared four GBRSs in Asia (i.e., GM, BEAM, TREES and CASBEE) with the BREAM and LEED and found that the examined GBRSs are similar in terms of criteria, approach, customer, and building types. However, due to the differences in the environment, society and economy, one scheme could "perform most effectively in one environment and might not be as effective in another" (Krajangsri & Pongpeng, 2018). Bansal et al. (2019) also assessed the BREEAM and LEED against two GBRSs in India (LEED-India and GRIHA). They acknowledged the popularity of LEED globally, the comprehensive coverage on the perspective of the sustainability of BREEAM, and the nascent stage of the two domestic GB schemes.

Furthermore, Doan et al. (2017) conducted a critical comparative review on four different green ratings, namely the BREEAM, LEED, CASBEE, and Green star New Zealand. They found that the core categories (such as Indoor Environment Quality, Energy, and Materials) of these green rating tools are similar. Among these four GBRSs assessed, only the BREEAM was found to evaluate four sustainable aspects: environment, social, economic, and institutional (Doan et al., 2017). Also, Varma and Palaniappan (2019) examined how 10 GBRSs across North America, Europe, and Asia (with LOTUS omitted) balanced the three pillars of sustainability and found non-uniform credit structures across the systems and a high proportion of energy weighting. This indicated that these GB rating tools are environmentally oriented. Finally, a systematic literature review and a selective critical literature review were conducted by Khan et al. (2019) to investigate how GB has evolved from a sustainable perspective. The results revealed that GB and its rating tools had not been adopted adequately in developing countries. Although GB provides higher benefits in all performance areas than conventional building, the authors indicated that the higher initial cost associated with the GB is the reason for its slow adoption. Therefore, besides revealing the long-term benefits of GB projects, GBRSs should be integrated with life-cycle costing to determine the cost of GB projects at the early stages of building projects.

2.1 Sustainable Development and Green Building

Sustainable development has become an environmental topic for discussion among the scientific community for many years; however, there is minimal consensus on what it means and the requirements for its promotion (Adebowale & Agumba, 2023; Baker, 2016; Goubran et al., 2023). According to Olakitan Atanda (2019), the first ideology of SD was given by the Brundtland Commission in 1987. It stated that SD is "a development which meets the needs of the present without compromising the ability of future generations to meet their own needs" (Farley & Smith, 2020). Varma and Palaniappan (2019) highlighted the environment, society, and economy as the three main pillars of SD, also known as the triple bottom line. In other words, the goal of SD is not only nature protection but also to create an ecological society that lives in harmony with nature (Baker, 2016; Li & Hai, 2023).

SD can also be considered a dynamic concept rather than establishing a static social, economic, and political structure. Its characteristics vary by time, location, cultural, social, political, and historical contexts (Baker, 2016). The commissioning of SD introduced the 'institution' as the fourth pillar of SD in 1995, which has gained significant recognition among scholars (Doan et al., 2017). Accordingly, the 'institution' could be described as the results of interpersonal processes, such as communication and cooperation, resulting in information and systems of rules governing the interaction of members of society. It can be indicated by various aspects, for instance, "a participator political system, non-discriminatory education, social security systems, gender equity, etc." (Spangenberg, 2002). Moreover, new pillars of SD, such as culture and epistemology, have been introduced (Doan et al., 2017).

The international sustainability goals have led to the development of the GB movement with unprecedented success (Abdelfattah, 2018; Karimi et al., 2023). Although the SD and GB terminologies are related and often used interchangeably, there are differences. GB is the practical tool for implementing SD as it helps mitigate the adverse impacts of the construction industry on the environment, society and economy (Thomas et al., 2023; Tseng et al., 2023; Varma & Palaniappan, 2019; Zhao et al., 2023), while the sustainable building is a part of the encompassing aim of achieving SD (Kabre, 2018). Earlier on, the GB rating systems mostly prioritised the technical and environmental aspects of SD (Novieto et al., 2023; Varma & Palaniappan, 2019). Accordingly, Cole (2006) described GBs as buildings that apply less environmentally and ecologically damaging design strategies than conventional ones. Nowadays, the importance of social aspects is being recognised and included in GB schemes (Shen & Li, 2023; Varma & Palaniappan, 2019), and the significance of buildings being economically reasonable to promote GB is also acknowledged (Chen et al., 2023; Copiello & Coletto, 2023; Varma & Palaniappan, 2019). As a result, the definition of GB encompasses a holistic approach to applying the triple bottom line concepts of SD. Hence, GB presents an opportunity to provide people with healthy, applicable, efficient space and harmonious natural architecture with the maximum savings on resources (energy, land, water, materials), protection for the environment, and reduced pollution throughout its whole life-cycle (Li et al., 2016).

2.2 Green Building Rating Schemes

2.2.1 LEED

LEED is one of the most recognised and commonly used GBRSs developed by the USGBC (Jalaei et al., 2020). The system is voluntary, consensus-based, and market-driven (U.S. Green Building Council, 2016). LEED aims to provide definitive standards for what constitutes a GB in design, construction and operation by using existing and proven technology to evaluate the whole perspective of a building over its life cycle (U.S. Green Building Council, 2016). The pilot version of LEED (LEED version 1.0) was initially launched in 1998, and until now, LEED has been through several significant updates (U.S. Green Building Council, 2016), as shown in Figure 1.

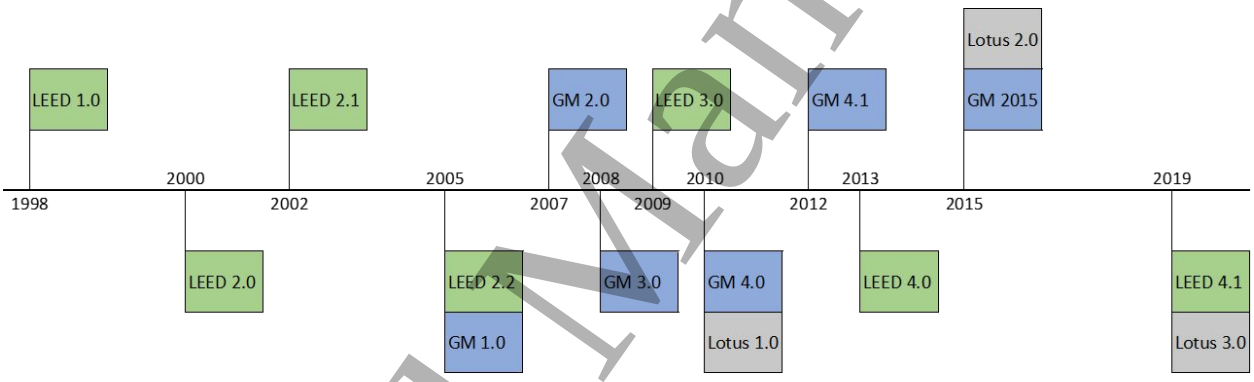

Figure 1: Development timeline of LEED, GM, and LOTUS

After over two decades of development, LEED has become the most popular GBRS globally based on the number of certified projects and countries adopting it (Amiri et al., 2019; Doan et al., 2017). As of June 2022, there were about 60,549 LEED-certified projects across 167 countries and territories (Green Building Information Gateway, 2022). The LEED rating schemes evaluate the sustainability of new and existing commercial, institutional, and residential buildings. Environmental factors account for the majority of the LEED assessment credits with 6 out of 9 main categories, including Location and Transportation, Sustainable Site, Water Efficiency, Energy and Atmosphere, Materials and Resources, and Indoor Environment Quality. Besides, LEED also acknowledges the importance of sustainable design expertise, design measures, and local conditions in its GB assessment by giving credits under the Integrative Process, Innovation, and Regional Priority categories (U.S. Green Building Council, 2016).

2.2.2 Green Mark

GM is a GBRS developed by the BCA of Singapore and was first released in January 2005 (Ting, 2012). The scheme is tailored for the tropical climate. It aims to enhance energy efficiency and the environmental performance of buildings by establishing parameters and indicators to guide the building design, construction, and operation (BCA, 2018). Since the first version launched in 2005, GM has evolved significantly and undergone four significant updates, see Figure 1. It applies beyond new and existing buildings and facilities to parks, infrastructures, districts, and transit systems (BCA, 2014). GM is considered one of South East Asia's leading GB rating systems, with 3408 projects certified so far and presented in 72 cities in 16 different countries (BCA, 2022). GM is structured into five sections: Climatic Responsive Design, Building Energy Performance, Resource Stewardship, Smart Healthy Building and Advanced Green Efforts.

2.2.3 LOTUS

LOTUS is a voluntary, market-based GBRS developed by the VGBC (Vietnam Green Building Council, 2019). The scheme aims to establish standards and benchmarks to guide the local construction industry towards more efficient use of natural resources and environmentally friendly practices, focusing on Vietnam's conditions (Vietnam Green Building Council, 2019). The first version of LOTUS was released in 2010, and since then, it has undergone two other significant updates in 2015 (LOTUS version 2.0) and 2019 (LOTUS version 3.0), see Figure 1. LOTUS can assess almost all building and project types via a range of programmes: LOTUS for New Construction, LOTUS for Building in Operation, LOTUS for Single-dwelling Home, and LOTUS for Interiors Fit-out (Vietnam Green Building Council, 2020c). In addition, LOTUS also evaluates building performance in seven key areas, including Energy, Water, Materials and Resources, Health and Comfort, Site and Environment, Management, and Exceptional Performance. According to the Vietnam Green Building Council (2020e), 34 LOTUS-certified projects with a total gross floor area of 295,530 m^2 by the end of 2020. These projects save 15,828,575 kWh of electricity and 5,700,147m^3 of water annually, compared to the baseline models (Vietnam Green Building Council, 2020e).

Table 1: Significant Features of LEED, GM, and LOTUS

	LEED	GM	LOTUS
Country	US	Singapore	Vietnam
Organisations	USGBC	GBA	VGBC
Flexibility	167 countries	16 countries	1 country
First version	1998	2005	2010
Latest version	2019	2018	2019
Number of mandatory criteria	12	15	9
Main categories	Integrative Process (1%) Location and Transportation (16%) Sustainable Sites (10%) Water Efficiency (11%) Energy and Atmosphere (33%) Materials and Resources (13%) Indoor Environmental Quality (16%) Innovation (6%) Regional Priority (4%)	Climatic Responsive Design (21.4%) • Leadership (7.1%) • Urban Harmony (7.1%) • Tropicality (7.1%) Building Energy Performance (21.4%) • Energy Efficiency (15.7%) • Renewable Energy (5.7%) Resource Stewardship (21.4%) • Water (5.7%) • Materials (12.9%) • Waste (2.86%) Smart and Healthy Building (21.4%) • Indoor Air Quality (7.1%) • Spatial Quality (7.1%) • SBO (7.1%) Advanced Green Effort (14.3%) • Enhanced Performance (10.7%) • Cost-Effective Design (1.4%) • Complementary Certifications (0.7%) • Social Benefits (1.4%)	Energy (32%) Water (13%) Materials & Resources (12%) Health and Comfort (14%) Site and Environment (21%) Management (8%) Exceptional Performance (8%)
Rating approach	Additive credits	Additive credits	Additive credits
Rating Level	Certified: 40-49 pts Silver: 50-59 pts Gold:60-79 pts Platinum: ≥ 80 pts	Gold: 51-59 pts Gold Plus: 60-69 pts Platinum: ≥ 70 pts	Certified: 40-54 pts Silver: 55-64 pts Gold:65-74 pts Platinum: ≥ 75 pts
Number of certified Building	60,549	3408	34

Table 1 presents the significant features of LEED, GM, and LOTUS. LEED has a vast number of certified projects among the three systems, with 60549 certified projects compared to 3408 projects by GM and 34 projects by LOTUS. The reason is that LEED was developed earlier than GM for over half a decade and LOTUS for over a decade, see Figure 1. Another reason is that while GM was aimed at tropical and sub-tropical regions and LOTUS was developed for the context of Vietnam only, LEED was oriented to be an international GBRS. The flexibility of LEED is due to its regular updates and revisions, hence, maintaining the leading role in the global GBRS landscape. LEED also allows using local and equivalent international standards to

assess its criteria. In contrast, most of the criteria of GM and LOTUS can only be assessed by their domestic codes, regulations, and standards.

All three rating systems use quantitative and qualitative criteria to evaluate the performance of buildings. Points are allocated to individual criteria based on their relative environmental impacts and human benefits in GB evaluation. The total point is then determined based on the rating level's criteria. LEED and LOTUS use Certified, Silver, Gold and Platinum as their rating levels, while GM rates building as Gold, Gold Plus and Platinum projects. Prerequisite credits are used in the three schemes to ensure the minimum requirements for all projects. For example, GM requires the project pursuing certification to meet 15 mandatory credits before detail assessment. The compulsory LEED and LOTUS GBRSs credits are 12 and 9, respectively.

These three schemes can assess the life cycle of various building types, such as residential, non-residential, school, health care, and retail buildings. However, only LEED and GM can evaluate facilities beyond buildings. Therefore, to assess sustainable construction on a large scale, LEED has developed LEED for Neighbourhood Development and LEED for Cities and Community. In contrast, GM has developed GM for Infrastructure, GM for Districts, and GM for Transit Stations.

3 Research Methods

This study combined the systematic literature review and the comparative method to examine GBRSs comprehensively. The research process is illustrated in Figure 2.

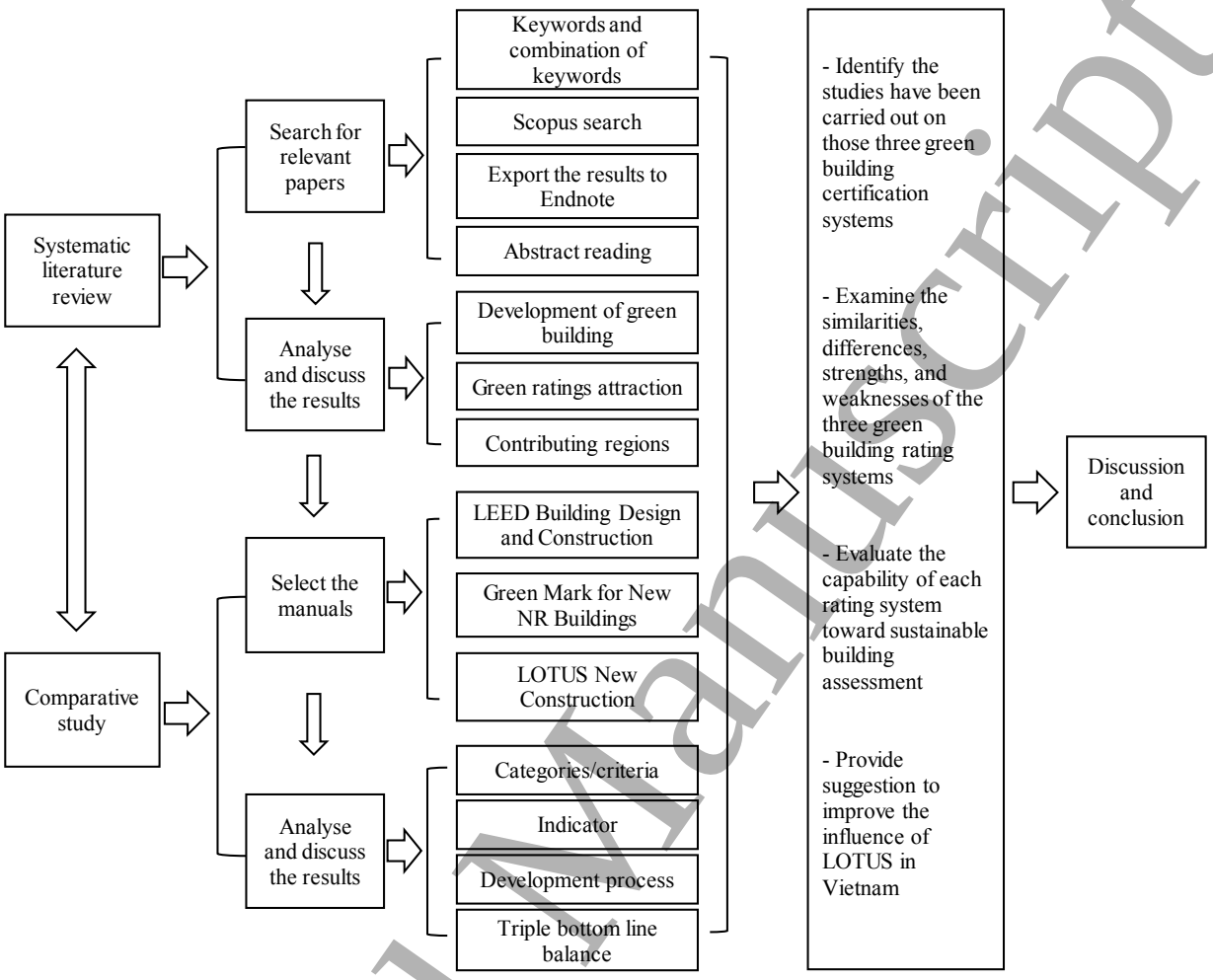

Figure 2: Research process

3.1 Systematic Literature Review

The literature review approach is a fundamental characteristic of research (Khan et al., 2019). Reviewing relevant literature helps researchers understand the width and depth of an existing field and identify the gaps to explore (Xiao & Watson, 2019). The systematic literature review is one of the techniques of literature review that begins with a specific review question, identifies all relevant studies, appraises their quality, and summarises their results using a scientific methodology (O'Brien & Mc Guckin, 2016).

In this study, the keywords "Green Building," "LEED," "the US," "LOTUS," "Vietnam," "GM", and "Singapore" were used for the systematic search to narrow down the result to the

most relevant. Afterwards, the following combinations of search terms (i) ("Green Building" AND LEED OR "the U.S."); (ii) ("Green Building" AND LOTUS OR Vietnam); and (iii) ("Green Building" AND "GM" OR Singapore) were inputted in the SCOPUS database under the "article title/abstract/keywords" field. The SCOPUS database was adopted for this study due to its broad coverage of various research fields (Doan et al., 2017). The result for each search term combination was exported and stored in the Endnote software manager to facilitate the systematic review and manage bibliographies, citations, and references. The abstracts were also read to eliminate irrelevant results. Only journal articles published under engineering-related fields in English and mainly focusing on at least one of the three GB schemes were considered relevant results for this study. Journal articles were preferred because they are typically the most cited and contribute more to developing knowledge than conference papers (Lin, 2011). Accordingly, the results were examined in-depth to determine the research interests of scholars worldwide on GBRSs.

Specifically, the following aspects were identified for this study: (i) the development of the GB concept; (ii) the popularity and the recognition of the three GBRSs; and (iii) countries currently adopting the GB concept.

3.2 Comparative Study

A comparative study is a suitable method to evaluate the effectiveness of GB rating tools and has been adopted by several scholars globally (Varma & Palaniappan, 2019). Accordingly, the manuals of LEED, GM, and LOTUS GBRSs were explored based on the following criteria:

i. ***Typicality***: LEED, GM, and LOTUS have several rating systems to evaluate a wide range of individual building types and other projects beyond buildings. To ensure a comprehensive comparison of these three GBRSs in the Vietnam context, new non-residential building manuals of the schemes were selected because they were adopted to evaluate the first versions of LEED, GM, and LOTUS. Therefore, these manuals would represent the main features of the three GBRSs. In addition, new non-residential buildings account for most certified projects and gross floor-certified areas in all three GB systems (Vietnam Green Building Council, 2020a, 2020d).

ii. ***Availability***: the manuals of the three GBRSs can be downloaded from their respective websites. However, the first versions of LEED and GM are no longer in use and are unavailable on their websites. Therefore, this study analyses the update process of the GBRSs based on the available versions of the three GB schemes. Specifically, the LOTUS version 1.0, LOTUS version 2.0, LOTUS version 3.0, GM version 2.0, GM version 3.0, GM version 4.0, GM 2015, LEED version 2.0, LEED version 2.1, LEED version 2.2, LEED version 3.0, LEED version 4.0 and LEED version 4.1 have been reviewed for this study.

iii. ***Measurability***: The selected manuals must have associated scores and assigned credits to be measured for quantitative comparison. Since the structure of LOTUS was developed based on that of LEED and GM (Vietnam Green Building Council, 2011), all three GBRSs are similar in structure.

The new construction/non-residential building manuals of the available versions of the three GBRSs were analysed at different levels (categories, credits, criteria), and other aspects such as development progress and balancing the three pillars of SD. The similarities, differences, strengths, and weaknesses of the three GBRSs were revealed at this stage. Since the scope of this study falls within the Vietnamese context, LEED, GM, and LOTUS were compared in conditions specific to Vietnam.

4 Findings and Discussion

4.1 Selection of Relevant Papers

From the systematic literature review Scopus search, a total of 562 journal papers published between 1998 and 2020 were discovered, from which 245 papers were eliminated for not mainly focusing on either LEED, LOTUS, or GM. Accordingly, 317 relevant papers were identified for further analysis, see Figure 3. Those papers were published in 137 different journals, and the Journal of Green Building contributed the highest number of papers linked to three GBRSs, with 40 papers. This was followed by Building and Environment and Energy and Building journals, with 27 and 14 papers, respectively, see Figure 4. The observed dominant proportions under LEED compared to GM and LOTUS may indicate LEED's advantage as one of the first GBRSs globally. This observation aligns with the position of LEED being the most

popular GBRS in the world (over 60,000 certified projects), as well as in Vietnam (93 certified projects) (Green Building Information Gateway, 2022; Vietnam Green Building Council, 2020a). In addition, Figure 4 shows the number of papers published in the eight prestigious journals identified, implying that the GB concept has gained popularity since the early 20th century and is of global concern.

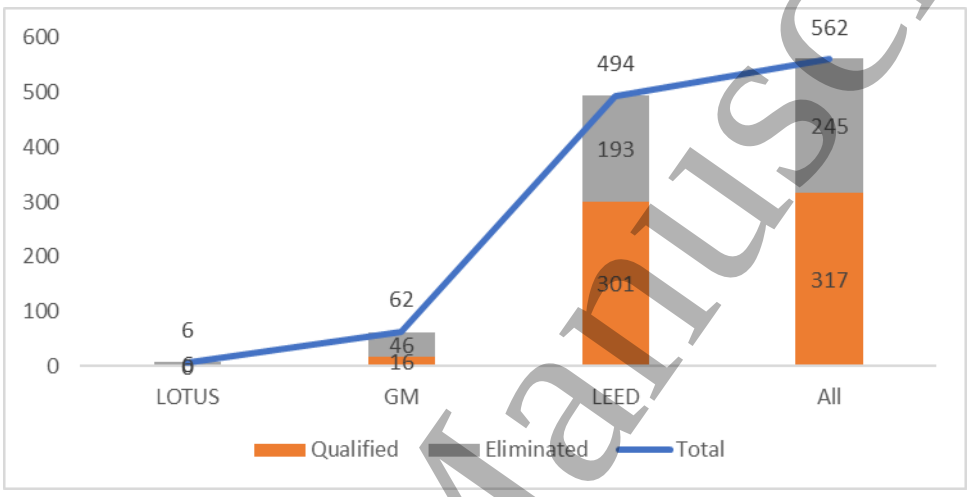

Figure 3: Number of the three GBRSs related papers found in the systematic literature review

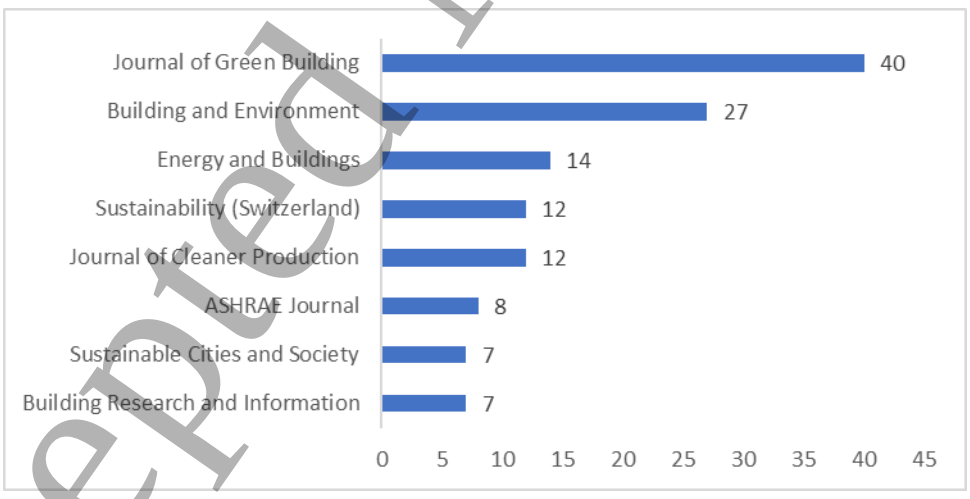

Figure 4: Number of the three GBRSs related papers by journals

4.2 Research Interest in LEED, GM, and LOTUS

From Figure 3, LEED has the highest number of publications, with 301 papers, followed by GM, with a wide margin of 16 papers. No paper was published under LOTUS to study its credit structure despite six results found using "LOTUS" as a keyword during the Scopus search.

It is evident from Figure 5 that the first paper published under the LEED GBRS was in 1998, a year after the release of its version 1.0. The number of papers started showing sharp increases from 2004, with 2019 experiencing the highest number of LEED-related publications. As also observed in Figure 5, the first GM-related paper was published in 2010, five years after the launch of GM version 1.0. An average of one GM-related paper was published in the following years, except in 2016 (three publications) and 2020 (four publications). The number of LEED-related papers found in the Scopus database is significant compared with that of GM and LOTUS, strengthening LEED's popularity and leading role in the world GB map. With 16 related papers published since its establishment in 2005, GM shows its attempt to be an outstanding GBRS in the Asian region. With no LOTUS-related paper found from the systematic literature review search, the LOTUS GBRS is still in its infant stage of proving its credibility for GB adoption in Vietnam.

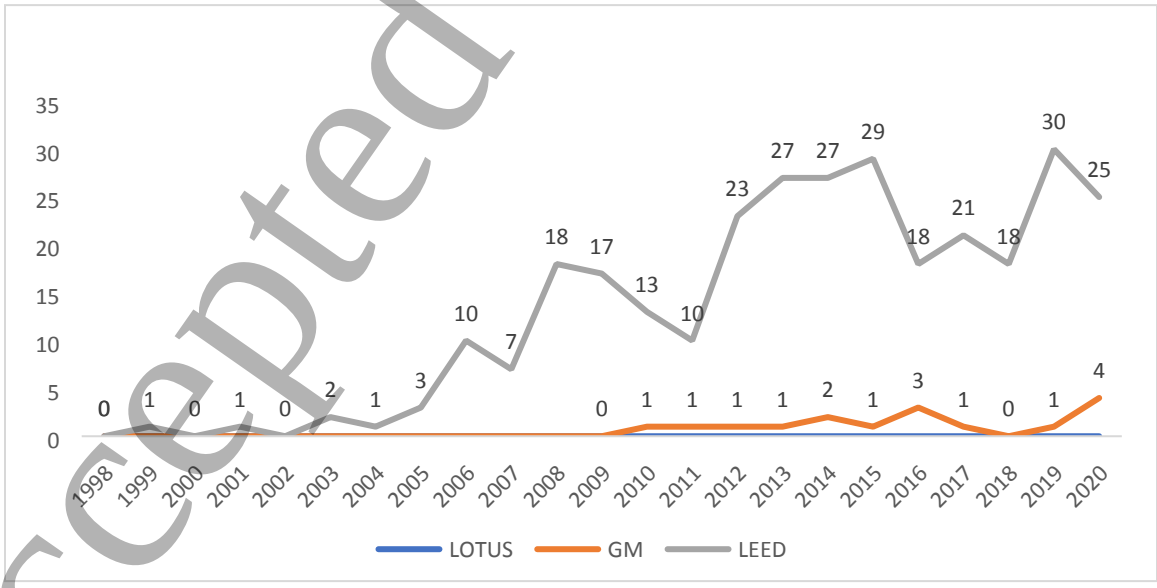

Figure 5: Number of the three GBRSs-related papers published from 1998 to 2020

4.3 Contributing Regions

The origin of 317 papers screened from the systematic literature review process was from 36 countries. Figure 6 illustrates the ten countries that have the most publications. Out of the 317 screened papers, 160 originated from the US, which is eight times higher than Canada's, with 20 papers. China followed closely with 17 papers. The other top countries are South Korea, Hong Kong, Australia, Singapore, Turkey, Egypt, and the UK, with around ten papers each.

It is also noted that 9 of the 16 GM-related papers originated from Singapore. The data reveal that LEED-related papers come from different continents (e.g., America, Europe, Asia, and Australia), see Figure 7. In contrast, GM-related papers come from countries with geographical proximity to Singapore (e.g., China, Hong Kong, and Australia), see Figure 8. This finding is compatible with LEED and GM's popularity in reality, as LEED is the leading GBRS worldwide, and GM is attempting to expand its influence outside of Singapore. The lack of papers identified for LOTUS indicates its less attractive even in the Vietnamese context. It is suggested that the VGBC put more effort into strengthening its ties with the academia, government, and construction practitioners both in and outside Vietnam to improve LOTUS's attractiveness.

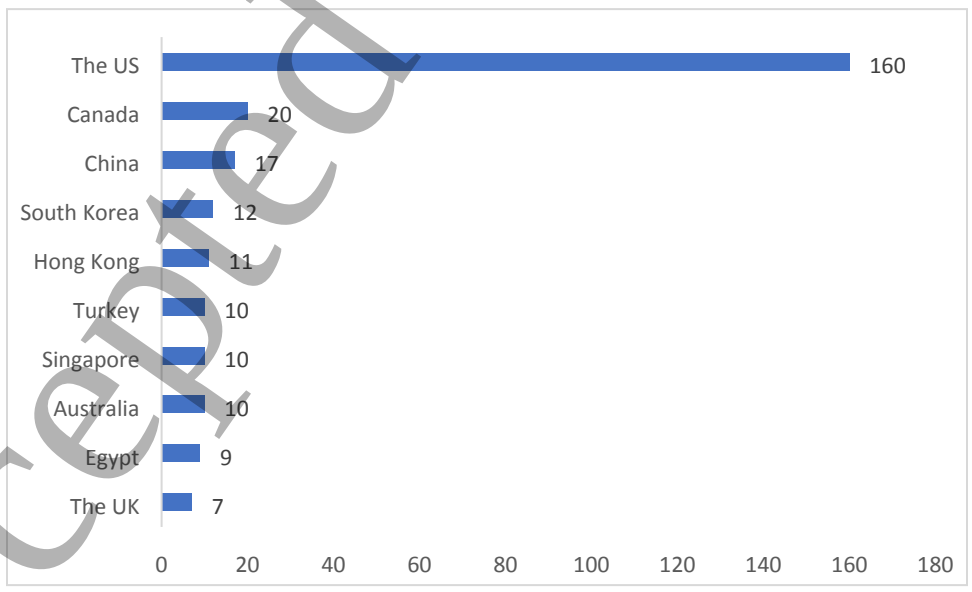

Figure 6: Number of the three GBRSs related papers published by countries

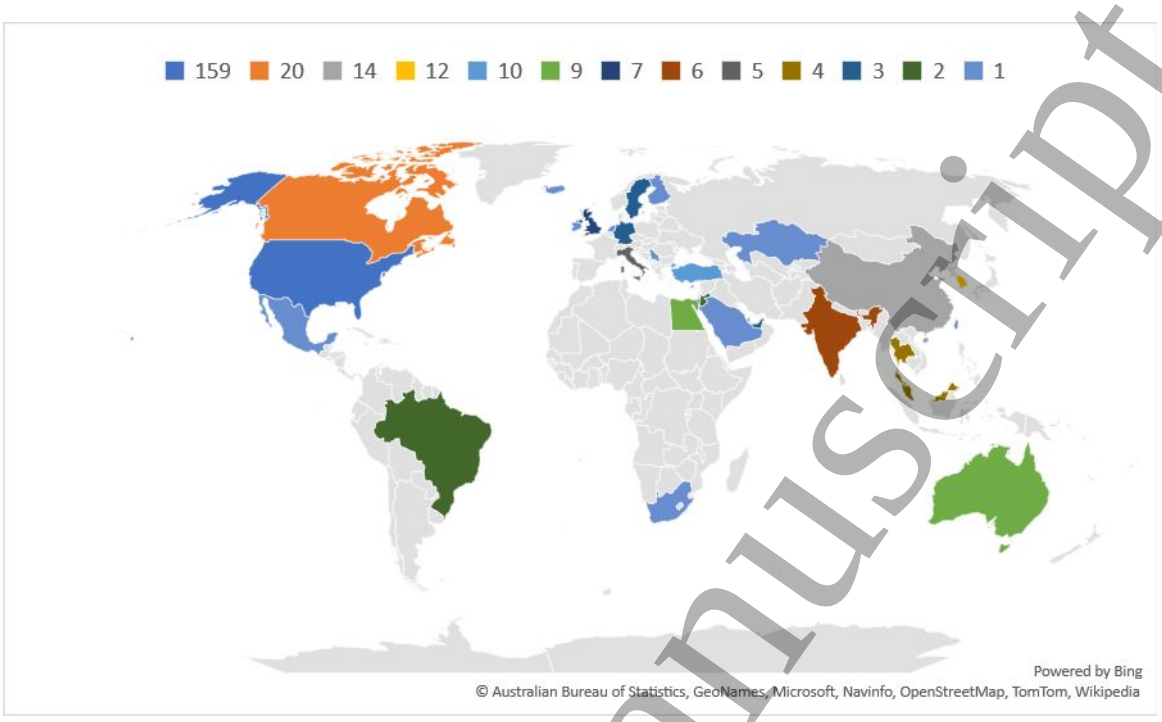

Figure 7: Number of LEED related papers published by countries

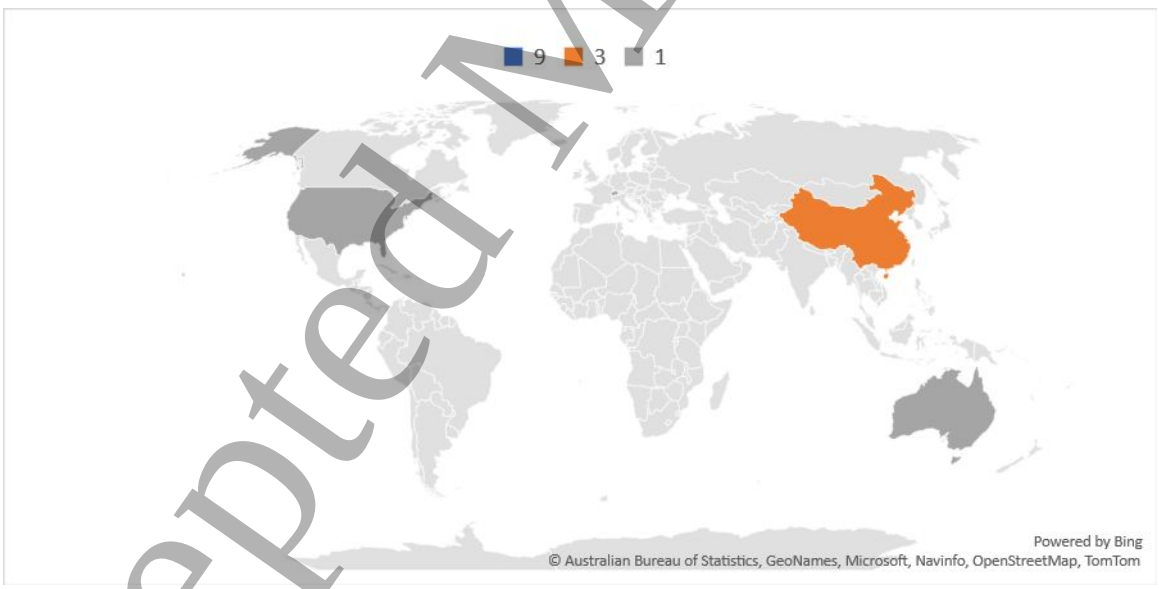

Figure 8: Number of GM related papers published by countries

4.4 Comparison of New Non-residential Construction Manuals of LEED, GM, and LOTUS

This study compared the new non-residential construction manuals of LEED, LOTUS, and GM, including the different versions of each GBRS. It can be observed from Figure 9 that

"Energy" is the leading category of the three GBRSs. Accordingly, LEED and LOTUS allocate one-third of their total points to energy in their latest versions, while GM allocates one-fifth of its total point to the energy category. The following priority aspects of LEED and LOTUS are "Site", "Location", and "Environment", with allocations of about 25% and 20% of their total points to these categories in their latest versions. In contrast, GM emphasises the "Climate Responsive Design" with a 21% allocation of its total points in this category. This finding could be linked to Singapore being an island country with a limited land area. Besides, "Water", "Materials", and "Indoor Environment" are the standard categories in all three GBRSs. These results show that despite conforming to the global GB movement, each GBRS is modified to support its development strategy and to be suitable for its origin country's natural, economic, and social conditions.

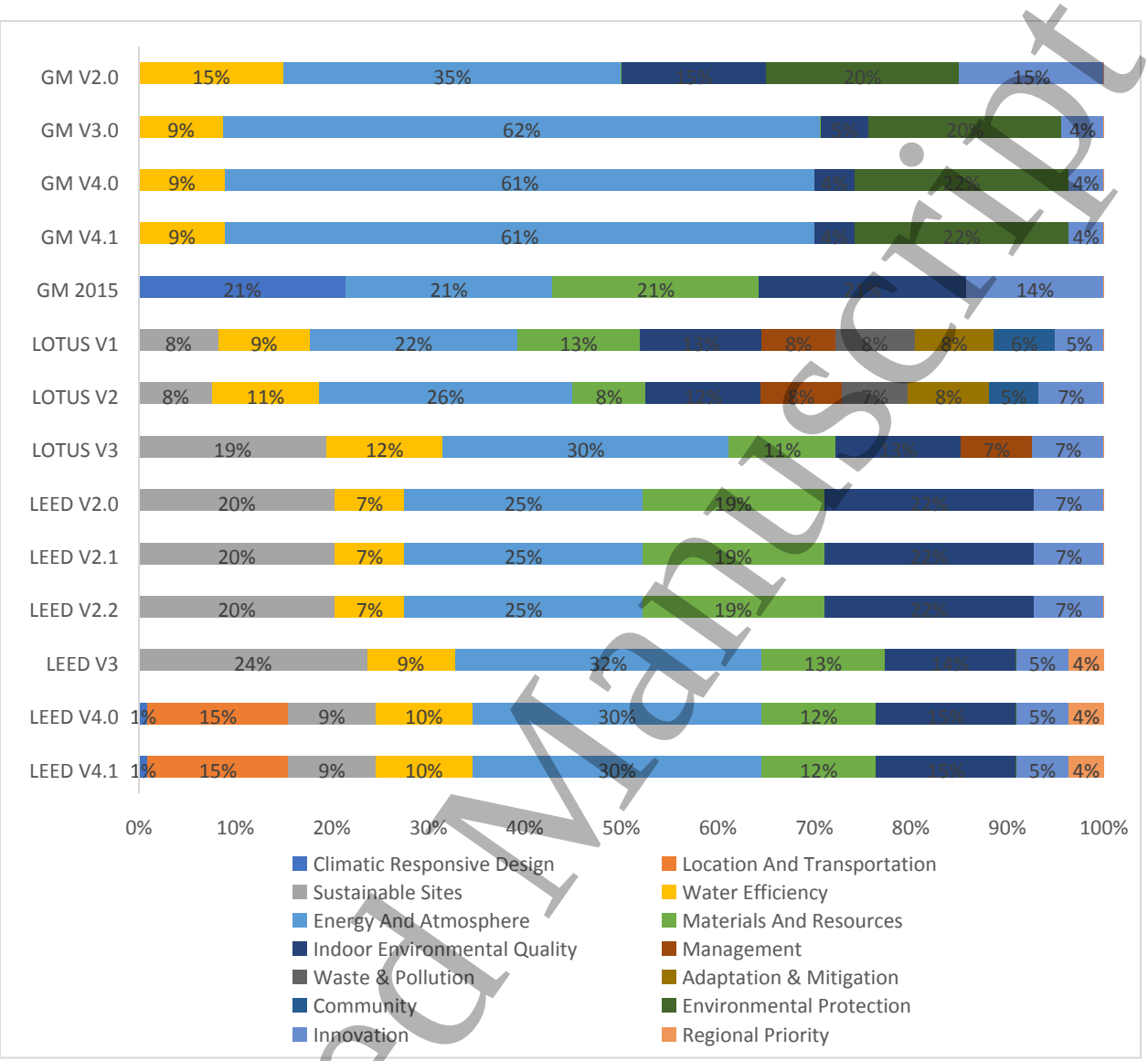

Figure 9: Credit structure of the three GBRSs

Figure 9 also shows that LEED and LOTUS are similar in terms of their credit structures. This is because both GBRSs were established by non-government third parties, with LOTUS's development influenced mainly by the LEED strategy. Hence, the Vietnam Green Building Council (2015) acknowledged that LEED is a focal point in the development of LOTUS. Despite using different terminology for their categories, both LEED and LOTUS focus on "Site Location", "Energy", "Water", "Materials", and "Indoor Environmental Quality".

LOTUS introduced the "Mitigation and Adaptation" category in versions 1 and 2, which aims to ensure that LOTUS-certified buildings can withstand natural disasters in the future, as

Vietnam is one of the five countries in the world most affected by climate change (Nguyen & Gray, 2016). However, the "Mitigation and Adaptation" category does not appear in LOTUS version 3, with its credits relocated to the "Site & Environment" category. This modification was made to simplify LOTUS for easier adoption by construction practitioners in Vietnam. As a result, the LOTUS categories were reduced from 10 in versions 1 and 2 to 7 in version 3. In contrast, the number of categories of LEED increased as it evolved. For example, there were 6 categories in the LEED version 2, modified to 10 in the current version 4.1. The new categories in the LEED's version 4.1 are "Integrative Process", "Location and Transportation", and "Regional Priority". These changes in LEED further strengthen its leading role in the global GB map and enhance its ability to assess GB performance comprehensively.

GM was established by a government agency and tailored to the specific conditions in Singapore and the tropical climate. The structure of its earlier was relatively straightforward with five categories, including "Energy Efficiency", "Water Efficiency", "Environment Protection", "Indoor Environmental Quality", and "Innovation". However, the version GM 2015, has been modified significantly to include 5 sections, 16 categories and 52 credits. The evolution of GM shows the desire for it to be the leading GBRS in the entire Asian region after affirming its role in Singapore.

In terms of points, all three GBRSs tend to change their credit points when newer versions are released. As credit points are calculated based on their relative environmental impacts and human benefits, they reflect importance in the assessment of GB when the version was released. For example, from Figure 10, the LEED versions 2.0, 2.1, and 2.2 maintained 69 points. Nevertheless, in version 3.0, the total points increased to 100, excluding ten bonus points for the "Innovation" and "Regional Priority" categories. The total points in the LEED version 4 remained unchanged at 100 base points and ten bonus points, but the credit points have been reallocated between credits and categories.

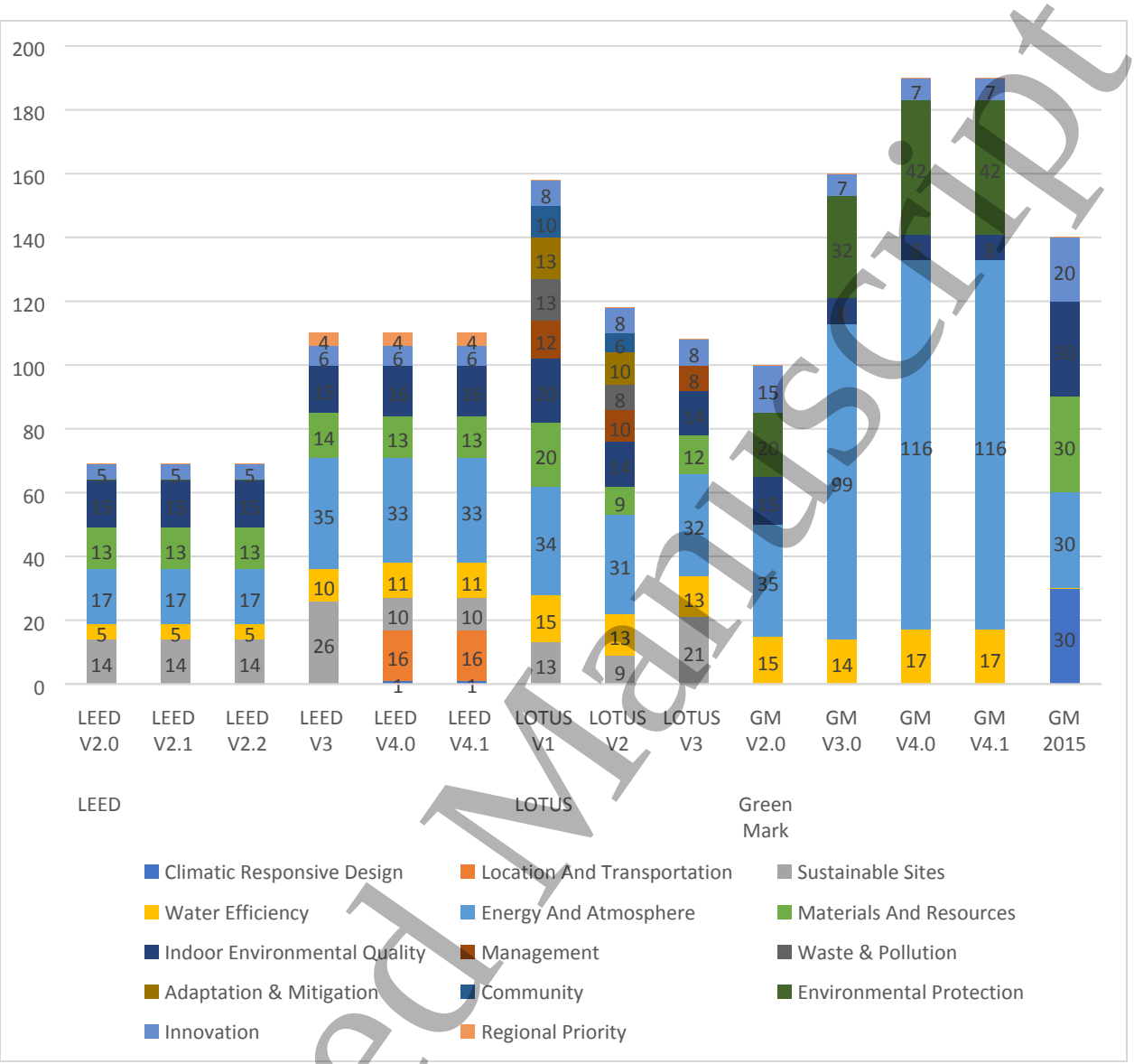

Figure 10: Point allocation of the three GBRSs

Furthermore, LOTUS witnessed a decreasing trend in total points in its later versions. While the base point of LOTUS version 1 was 150, it was reduced to 110 and 100 in versions 2 and 3. However, the bonus points of 8 remained unchanged for the "Innovation" category. GM is different from LEED and LOTUS due to its non-consideration of bonus points for innovation. While GM version 2.0 had 100 points, its version 3.0 had 160 total points, which was increased to 190 in versions 4.0 and 4.1. Version GM 2015 has its total points decreased to 140 points and allocates the points equal to its four main categories, 30 points each, and the fifth category, 20 points.

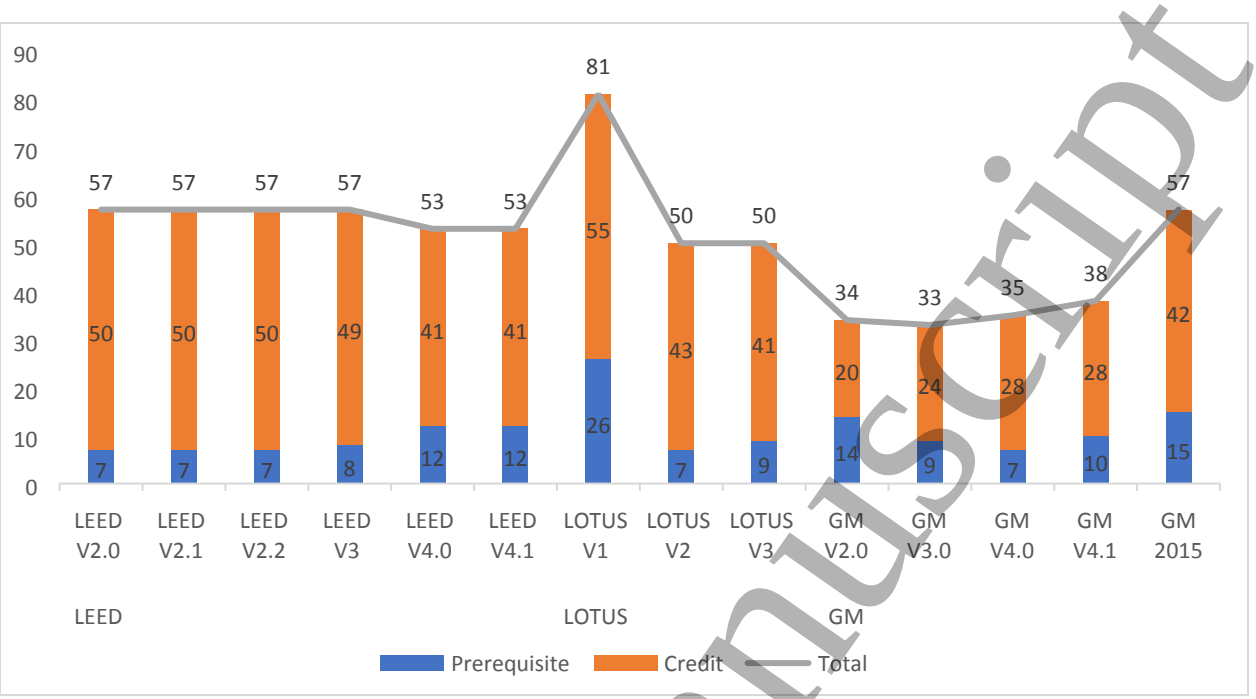

Figure 11: Number of prerequisites and non-mandatory credits

All three GBRSs use prerequisite credits to define the minimum requirement for a building project to be eligible for certification. In this case, the point is not allocated to the prerequisite credit. A slight change was observed in the number of credits in the later versions of LEED. For example, the LEED earlier versions 2.0, 2.1, and 2.2 had 7 prerequisite credits and 50 non-mandatory credits, while the later versions 4.0 and 4.1 had 12 prerequisite credits and 41 non-mandatory credits, see Figure 11. On the other hand, LOTUS significantly reduced the number of credits in its current version compared to the earliest one. LOTUS had prerequisite and non-mandatory credits of 26 and 55, respectively, in version 1, and 9 and 41, respectively, in version 3.

In contrast, GM increased the number of prerequisite and non-mandatory credits from 14 and 20, respectively, in version 2 to 15 and 42 in version GM 2015. Consequently, these findings indicate that LEED and GM have evolved to assess the GB concept more comprehensively, affirming their role in the global GB map. At the same time, LOTUS is still struggling to catch up with the global GB movement and reinforce its influence in Vietnam.

Table 2 presents an analysis of the credits of the current LEED, LOTUS, and GM versions and their classification into the three pillars of sustainability, see Figure 12. Specifically, the underlying objectives of the three GBRS credits have been examined to determine their complete alignment with the pillars of 'Environment', 'Society', or 'Economy'. Each corresponding credit's point value is then apportioned under its relevant category and pillar. This apportionment is based on the total points attributed to each category relative to the overall point system of the GBRS. Using this information, the categories and established proportions supporting each facet of sustainable development were identified. This process ensures a comprehensive and clear depiction of the extent to which each sustainability pillar is being supported. It is clear from Table 2 that "Environment" is the aspect that all three GBRSs support the most, with LEED having the highest proportion (76.4% of its total points), closely similar to LOTUS (75%). However, GM prioritises "Society" since over a third of its points are allocated to evaluate the Society pillar of sustainability; this almost doubles the figures of LEED and LOTUS. Only a few points are assigned to "Economy" aspects, indicating the weakness of these three GBRSs. In other words, it is inappropriate to conclude that either LEED, LOTUS, or GM is a sustainable rating system because they cannot assess the Economic aspects of construction projects.

Table 2: *A comparison of the three pillars of sustainability by credits*

Sustainability	LEED	LOTUS	GM
Environment	Location & Transportation (13.7) Sustainable Sites (8.2) Water Efficiency (9.1) Energy & Atmosphere (29.1) Materials & Resources (11.8) Innovative (4.6) **Total = 76.4%**	Energy (26.9) Water (11.1) Materials (11.1) Site & Environment (13.0) Management (5.6) Exceptional Performance (7.41) **Total = 75.0%**	Building Energy Performance (21.4) Resource Steward (20) Smart & Healthy Building (5) Advanced Green Efforts (11.4) **Total = 57.9%**
Society	Integrative Process (0.9) Location & Transportation (0.9) Sustainable Site (0.9) Indoor Environment (14.6) Innovation (0.9) Regional Priority (3.64) **Total = 21.8%**	Energy (0.9) Health & Comfort (13.0) Site & Environment (6.5) Management (1.85) **Total = 22.2%**	Climatic Responsive Design (21.4) Smart & Healthy Building (14.3) Advanced Green Efforts (1.43) **Total = 37.1%**
Economy	Water Efficiency (0.9) Energy & Atmosphere (0.9) **Total = 1.8%**	Energy (1.9) Water (0.9) **Total = 2.8%**	Resource Stewardship (1.4) Smart & Healthy Building (2.1) Advanced Green Efforts (1.4) **Total = 5.0%**

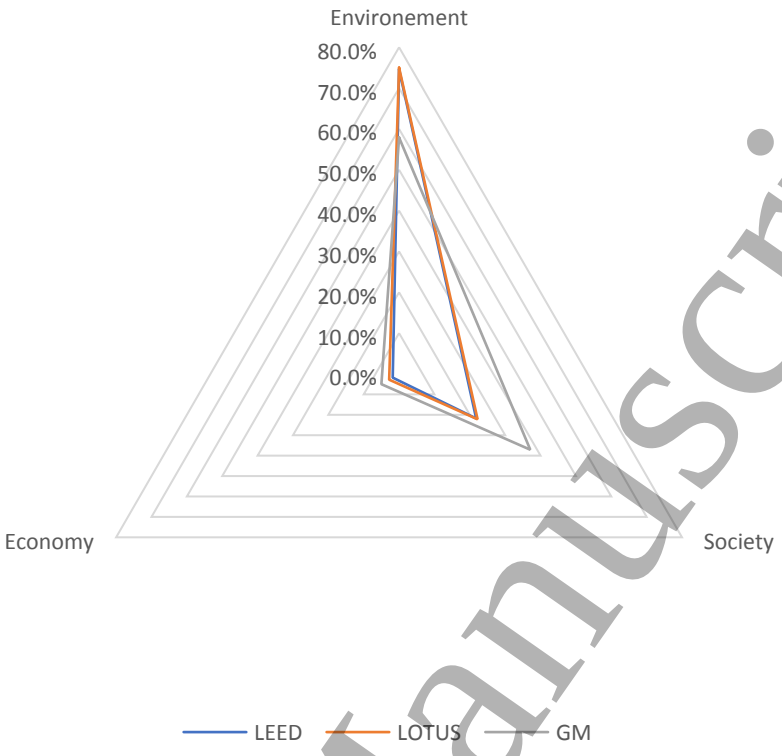

Figure 12: Sustainable development assessment of LEED, LOTUS, GM

Results from the comparison of new non-residential construction manuals of the three GBRSs indicate that LOTUS can comprehensively assess the performance of green buildings. However, the complexity of its first version is one of the primary reasons that have inhibited LOTUS from vast recognition in its home country, Vietnam – a developing country where the GB concept is still a new definition. Therefore, it is recommended that LOTUS be simplified to the existing level of construction development and GB awareness in Vietnam before evolving to evaluate the tenets of sustainable development more holistically.

4.5 Further Discussion

Findings from the systematic literature review revealed the comparison and analysis of three typical GBRSs applicable to the Vietnamese scientific society and reflected their global popularity. With 301 relevant papers published from 36 countries, LEED was identified as the most popular of all three GBRSs, followed by GM, with 16 relevant papers originating from 6 countries. LOTUS was the least popular, with no relevant paper from the systematic literature review. These findings align with an existing study that reviewed the performance of GBRS

regarding the number of certified projects and the number of countries adopted (Doan et al., 2017). Accordingly, LEED has always been an attractive topic for researchers to incorporate into their studies based on the rigour of its performance development.

On the other hand, GM has continued to affirm its role in Singapore after about 15 years of its inception and has started to aim at other tropical countries in the Asian region (Ting, 2012). Despite being introduced over ten years, LOTUS is still in its infant stage of gaining a substantial role in GB's popularity and adoption in its home market, Vietnam (Nguyen et al., 2017). The large number of papers studying LEED is vital in facilitating its leading position and promoting GB adoption worldwide.

All three assessed GBRSs update their new non-residential construction manuals to catch up with sustainable construction movements and development strategies. LEED has been capable of assessing the performance of GBs comprehensively, which has been demonstrated through the less frequency of releasing newer versions and the similarity in the credit structure of its later versions. The first versions of GM were quite simple. For instance, GM version 3 only had 5 categories with 24 non-mandatory credits and 9 prerequisites. The simple structure of GM's first versions helped it gain easy acceptance in Singapore. The structure with 5 categories was kept until the commissioning of GM version 4.1, before GM 2015. The credits in the GM 2015 are structured into 5 sections, with 16 criteria and 52 indicators. This change indicates how GM has built a firm foundation in Singapore and expanded to other tropical countries in the Asian region. LOTUS, in contrast, had a different approach when it established its first version. LOTUS version 1 had ten categories with 26 prerequisites and 55 non-mandatory credits. In a quest to simplify the later versions, LOTUS version 3 had its number of categories reduced to 7 with only 9 prerequisites and 41 non-mandatory credits. The intricacy of its initial version serves as a barrier, limiting its influence within Vietnam. A more balanced development strategy, which considers the current level of understanding and attitude towards GB among Vietnamese practitioners, should be considered.

Regarding the three pillars of sustainability, “Energy” accounted for more than half of the total points for all three GBRSs, implying that their primary focus is on environmental aspects. Consequently, the “Energy” category accounts for the highest points in all three GB assessment

tools. Among the three assessed GBRSs, "Energy", "Water", "Materials", and "Indoor Environment" have the same categories, with only GM being able to evaluate sustainability more harmoniously.

Table 3 summarises the strengths and weaknesses of LEED, LOTUS, and GM, drawn from the systematic literature review and the comparative study. One striking feature is the assessment coverage of each system. Both LEED and GM have expanded their assessment criteria beyond individual buildings to incorporate wider community and infrastructure considerations. This holistic approach to sustainable development is currently absent in the LOTUS system. Hence, LOTUS might benefit from broadening its scope to include wider environmental and social factors, such as neighbourhood development and transit planning. While having global reach, the LEED system shows a limitation in its assessment of economic factors. This is an area that could be improved upon. For instance, considering the cost-effectiveness and financial benefits of sustainability measures could provide a more comprehensive evaluation of a building's impact and performance.

Table 3: *Strengths and weaknesses of three GBRSs*

	LEED	**LOTUS**	**GM**
Establishment	Non-profit third party	Non-profit third party	Government agency
First version launched in	1998	2010	2005
Main market	Worldwide	Only in Vietnam	Countries in Asia with the tropical climate
Building' life-cycle assessment	Design, Built, Operation, Innovation and Maintenance	Design, Built, Operation, Innovation and Maintenance	Design, Built, Operation, Innovation and Maintenance
Beyond building assessment manual	Neighbourhood Development manual, Cities and Community manual	None	Infrastructure manual, District manual, Transit Station manual
Attraction	Global researchers and organisations	None	Global researchers and organisations
Credit structure	Clear and flexible	Complex in the first version, simplified in later versions	Simple in early versions, well-structured in the latest version
Mandatory credits	Use	Use	Use
New Construction Non-residential manual			
• ***Environment***	Sufficient assessment	Sufficient assessment	Sufficient assessment
• ***Society***	Barely sufficient assessment	Barely sufficient assessment	Sufficient assessment

• ***Economy***	Limited assessment	Limited assessment	Limited assessment

The complexity of LOTUS's initial version has proven to be a barrier to its adoption in Vietnam. This suggests that a more user-friendly design would enhance uptake. A clear, well-structured and simple-to-understand system, similar to the improvements seen in the GM system, could make the LOTUS rating system more appealing to practitioners in Vietnam. Lastly, despite its robust structure, the GM system is primarily limited to tropical climates in Asia. There could be potential for expanding its application to other climatic conditions and regions. By doing so, its appeal and influence could be enhanced, leading to broader adoption of its sustainability principles.

Overall, these insights highlight the importance of continued evolution and improvement in GBRSs, to ensure they meet the diverse needs of users and contexts in which they are applied. This is crucial to promote the widespread adoption of sustainable building practices globally.

5 Conclusion and Recommendation

This study combined a systematic literature review and a comparative study to analyse the effectiveness of LOTUS against LEED and GM. The results showed that LEED was the most popular GBRS adopted in Vietnam. The construction industry is an integral part of the economy and a significant environmental polluter. Therefore, GB has been considered as an effective solution to mitigate the negative impacts of the built environment on nature. In Vietnam, the GB concept has been introduced for more than a decade; however, the effectiveness of GB in Vietnam is still limited. Accordingly, Vietnam's LOTUS is less recognised than the popularity and acceptance of the US's LEED and Singapore's GM.

It is recommended that more efforts be made to enhance the recognition and acceptance of LOTUS in Vietnam's GB-related academic and industry sectors. Besides, the focus of LOTUS should be on the core criteria of the GB concept (energy, water, materials, and indoor environment) to simplify its design. Hence, balancing the level of construction development in Vietnam facilitates Vietnamese construction practitioners' awareness and adoption of the GB concept. Furthermore, the Vietnamese GB authorities can apply the findings from this study as a

reference toward making LOTUS more suitable for GB construction conditions in Vietnam, supporting the promotion of GB adoption in the country.

The insights gained from this research pave the way for intriguing possibilities for future studies. Specifically, incorporating a case study is a promising area of exploration. The value of comparing the scores of a particular building across LEED, LOTUS, and GM cannot be overstated. A detailed comparative study could offer a comprehensive and practical understanding of how these rating systems function in a tangible, real-world context. It could also highlight how these systems impact decisions made during the design and construction process. Additionally, an in-depth examination of the specific standards employed within the credits of these rating systems could provide a wealth of benefits for construction practitioners and building owners, albeit a complex task that demands expertise from various fields.

While the research offers a comprehensive analysis of the LEED, LOTUS, and GM rating systems, a minor limitation in the review of literature is acknowledged. The research primarily draws upon literature available up until a specific cut off point, which means more recent publications from the last three years are not extensively included in the analysis. However, given the enduring relevance of the foundational principles and trends examined, the absence of these recent studies does not significantly impact the overall validity of the findings.

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Data Availability Statements

No new data were created or analysed in this study.

Ethical Approval

Ethics approval is not required in this research.

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