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A critical comparison of green building rating systems

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ABSTRACT

Various green rating systems are established globally to evaluate the sustainability of construction projects. Their categories and criteria have been under constant updates to follow the sustainable trend of building development. This paper aims to develop a systematic review of the development of green rating systems. The specific objectives are: 1) discover how interest and research in green rating systems have developed; 2) identify the similarity, difference, strength and weakness of green rating systems; 3) examine whether they fully assess the projects in all aspects of sustainability. Specifically, LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Establishment Assessment Method), CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) and Green Star NZ were analysed in this paper. The results indicate that BREEAM, LEED, and CASBEE have been utilized since late the 2000s while Green Star NZ is still in its earlier stages. 70% of the research papers focusing on BREEAM, LEED, CASBEE are developed geographically in the USA, Canada, the UK, China, and Australia. Although these four rating systems were initiated in different contexts with different standards, Indoor Environment Quality, Energy, and Material are core common categories for all. Environmental concerns are the main focus in New Construction manuals while Society is emphasized in Neighbourhood Development manuals. Currently, BREEAM has been the only tool which could assess all four sustainable factors. Further in-depth research is anticipated to focus more on economic and institutional factors to improve the capability of green rating systems for sustainability assessment purposes.

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1. Introduction

The construction industry plays an important role in satisfying the needs of society, enhancing the quality of life [1–3], and contributing to the economic growth of a country [3–6]. However, it has been heavily criticised for being a major contributor to carbon emissions, environmental degradation, and global warming [7–11] due to its utilization of a large proportion of natural resources and energy consumption [11–14]. The building sector consumes a third of global resources [15,16], one sixth of global freshwater withdrawals [17], 25% of wood harvested [16], and 40% of all raw materials [16]. Approximately 10% of all global energy supply takes place during the manufacturing of building materials [10,15]. Also, the building sector generates a large amount of construction and demolition waste, accounting for 40% of total solid waste in developed countries [18–20]. Moreover, the construction industry is responsible for major energy consumption, accounting for 40–50% of all energy usage and anthropogenic greenhouse gas emissions globally [21–25].

Recognizing the importance of sustainable building practices, “going green” and “environment sustainability” has been introduced for many years [10,26]. However, construction is still a major energy consumer based on official statistics [10]. This could be due to the passive attitude of construction practitioners towards adopting sustainable solutions [7]. Facing the rising energy costs and growing environmental concerns, the demand for sustainable building facilities with minimal environmental impact has been pushed recently [27–29].

Authorities and organizations initiated the rating systems for green buildings to minimize/optimize consumption of natural resources and control pollution. Buildings certified by those rating systems are considered as consuming less energy, providing a better living environment and contributing to the overall reputation of the property [30]. It is estimated that there are approximately 600 green rating systems globally [31]. BREEAM (Building Research Establishment Assessment Method) is known as the first rating tool to assess building performance based on certain target values for different criteria [32–34]. In addition, numerous schemes such as the United States' LEED (Leadership in Energy and Environmental Design), Canada's LEED Canada, France's HQE (High Environmental Quality), Germany's DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen e.V.), Australia's Green Star, New Zealand's Green Star, Japan's CASBEE (Comprehensive Assessment System for Building Environmental Efficiency), Hong Kong's BEAM (Building Environmental Assessment Method), Singapore' BCA (Building and Construction Authority) Green Mark Scheme are currently being utilized to evaluate building performances. BREEAM certified buildings could consume 6–30% lower energy costs than non-certified buildings [35,36] while LEED certified properties consume 18–39% lower energy usage than non-certified properties [35,37–39]. However, the focus on green credentials evidenced such as LEED misses the larger picture, sustainable aspect [40]. According to Berardi [41], and Runde and Thoyre [40], the impact of sustainability will extend far beyond green buildings in the near future. Concerning this, all leading green building rating systems have been continuously updating their criteria. LEED had a major update in 2013 with LEED v4, and it just updated its rating tools in mid-2016 [42]. While the major update to BREEAM happened in mid-2014 with BREEAM UK New Construction [43]. Mid-2015 and mid-2016 saw the latest version of Green Star Australia and Green Star New Zealand respectively [44,45]. Besides, international standards about sustainable buildings have also created. For example, ISO/TC 59/SC 17 was created in 2002 to implement aspects of sustainability in the building sector [46].

Although green building rating certifications have been the focus of various researchers during the past 20 years, there is still no systematic review of the detailed criteria and the updated process of each rating system. A number of papers focused on the trend and credits in an individual rating tool, however, a comprehensive comparison of tools has not been established. For example, Todd [47] focused on the global trends in LEED-NC and LEED-EBOM besides investigating the achievement of individual LEED credits. Murakami [48] introduced the concept and framework of the CASBEE-City. Cheng and Ma [49] adopted data mining techniques to examine the relationship between LEED credits and climate factors. While other researchers made comparisons among green rating schemes, studies to examine the update and the global trend of those schemes together or research about their capability in promoting the sustainability are lacking. Lee and Burnett [50], for instance, analysed the energy use assessment of HK-BEAM, BREEAM, and LEED. Schwartz and Raslan [37] examined the impact of building energy simulation tools on BREEAM and LEED ratings. Ng [52] tried to find out the properties and standards of various building environmental assessment ratings on evaluating carbon emissions. Besides research papers, projects focusing on sustainable indicators for buildings had also been carried out. For example, Super Buildings project funded by European Commission was conducted during 2010–2012 by leading European organizations and companies [53]. However, this project focused more on the European context where BREEAM is accounting for 80% of the market [43,54–56], which may not provide an inclusive view. This paper, therefore, aims to develop a systematic review of the development of green rating systems focusing on the well-known global schemes with LEED in the Americas, BREEAM in the Europe, CASBEE in the Asia, and Green Star in the Australasia. The specific objectives are:

1. Discover how interest and research in green rating systems have developed
2. Identify the similarity, difference, strength, and weakness of green rating systems
3. Examine whether they fully assess the projects in all aspects of sustainability.

2. Green vs sustainable buildings

Green and *Sustainable* building have been used interchangeably [10,40,41,57], but these two terms are far from synonymous [40,41,57]. Cole [58] described *Green* as “*building design strategies*

that are less environmentally and ecologically damaging than typical practice" [59,60] in 1999. While Kua and Lee [61], and Yoshida and Sugiura [62] defined *Green* building as "*one that meets certain criteria for environmental performance*" [61]. In 2008, it was indicated that *Green* is "*a term encompassing strategies, techniques, and construction products that are less resource-intensive or pollution-producing than regular construction*" [63]. Howe [64] detailed it as using land and energy efficiently, conserving water and other resources, improving indoor and outdoor air quality, and increasing the use of recycled and renewable materials. The concept of *Green* building has been continually revised and its definition is commonly accepted as "*providing people with healthy, applicable, efficient space and natural harmonious architecture with the maximum savings on resources (energy, land, water, materials), protection for the environment and reduced pollution throughout its whole lifecycle*" [65–67].

The definition of *Sustainability* has also suffered from ambiguity and uncertainty [41,68,69]. New definitions incorporating over 100 concepts have been given [41]. One of the earliest of its definitions was given by Brundtland Commission in 1987, which stated that "*sustainable development is a development which meets the needs of the present without compromising the ability of future generations to meet their own needs*" [41,70,71]. Although *Sustainability* has been defined concerning diverse aspects, environmental, social, and economic impacts are its three main pillars [72–77]. Recently, the fourth pillar, institutional dimension, has gained increasing recognition [75,78–80]. Institution was introduced as the fourth pillar in 1995 by the Commission on Sustainable Development [81]. It is defined as "*the results of interpersonal processes, such as communication and co-operation, resulting in information and systems of rules governing the interaction of members of a society*" [82]. Its indicators, used to evaluate the institutional sustainability, were suggested by the United Nations focusing on several aspects such as a participator political system, non-discriminatory education, social security systems, gender equity etc. [81,83].

It is clear that the concepts for both *Green* and *Sustainability* are simple and can be considered vague in the beginning. However, they can be clarified in detail step by step. There are factors created to evaluate how *Green* buildings are more environmental and ecological than the traditional ones such as energy, land, water, and materials. While four main pillars are identified to determine the *Sustainability* of a project. It is noticed that although the definition of *Green* has still been developing, the environment is always its core. Whereas, *Sustainability* could be considered as a non-stop development concept depending on the sustainable building practices. This is because *Sustainability* is multi-interpretations and an interdisciplinary concept [81,84], and the difference in current sustainable construction practices is occurring due to the various concepts of sustainable construction among countries [85]. Wangel [86] stated that *Sustainability* should be a normative concept established for a particular purpose than defining inductively. Shari and Soebarto [60] believed that *Sustainability* could embrace all facets of human activity, and Yanarella [57] considered it as a concept tied to the whole systems.

Up to date, *Green* (GRE) buildings embrace environmental improvements while *Sustainable* buildings focus on four main pillars, including environmental (ENV), social (SOC), economic (ECO), and institutional issues (INS) [78], see Fig. 1. With the continuous update on the definition, it is anticipated that more and more pillars will be established to assess the *Sustainability* of building practices. Council [87], Cities and Governments [88] suggested *Culture* could be the next dimension of *Sustainability* while Redclift [89] determined *Epistemology* is one of *Sustainability*'s dimension.

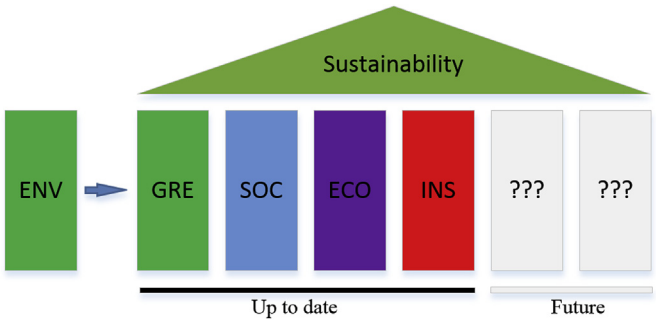


Fig. 1. Sustainable framework.

3. Green rating systems

During this study, BREEAM, LEED, CASBEE, and Green Star NZ, were analysed in detail. The rationale to select these rating systems is based on considering BREEAM, LEED, and CASBEE as globally well-known leading ones alongside Green Star NZ, which in comparison is a relatively new system that has recently released its latest version and New Zealand has subsequently seen a significant increase in the number of registered green buildings.

3.1. BREEAM

BREEAM is seen as the first green building rating assessment in the world, launched and operated by BRE (Building Research Establishment) in the UK [32–34]. It was introduced to the market in 1990 and was first revised to assess offices in 1993 [33,90]. It is widely accepted that almost all later major green rating systems such as LEED, Green Star, and CASBEE are under the influence of BREEAM (Fig. 2).

BREEAM is widely used owing to its flexibility. It not only assesses local codes and conditions but also allows application in international buildings [91]. In addition, BREEAM enables evaluation of a building's lifecycle in view to design, built, operation and refurbishment; BRE provides New Construction, In-use, Refurbishment and Fit-Out, Communities, and Infrastructure manuals for planners, local authorities, developers, and investors. As a result, BREEAM has so far issued over 560,000 certifications [43]. This number is anticipated to follow its increasing pattern (from 250,000 buildings in 2014 [92] to 425,000 buildings in 2015 [93], and 540,000 buildings in 2016 [56]). A similar incremental pattern applied to the number of countries adapting BREEAM since 1990 (50 countries in 2014 [92], 70 countries in 2016 [56], and over 75 countries in 2017 [43,94]). BREEAM certifications accounts for 80% of the European market share for sustainable building certifications [43,54,55,95]. Although all of the sustainability pillars could be assessed by BREEAM, the environmental factor is still predominant with eight main categories including *Management, Energy, Transport, Water, Materials, Waste, Land Use & Ecology,* and *Pollution*.

3.2. LEED

LEED is a voluntary standard developed by USGBC (US Green Building Council) [97,98]. It was first launched in 1998 with a pilot version (LEED 1.0) [99,100]. Although it was released after BREEAM, it is considered as the most widely adopted rating scheme based on the number of countries, with over 79,000 projects [42,101,102] across 135 countries in 2012 [103,104], reaching nearly 150 countries and territories in 2014 [92], and over 160 countries and

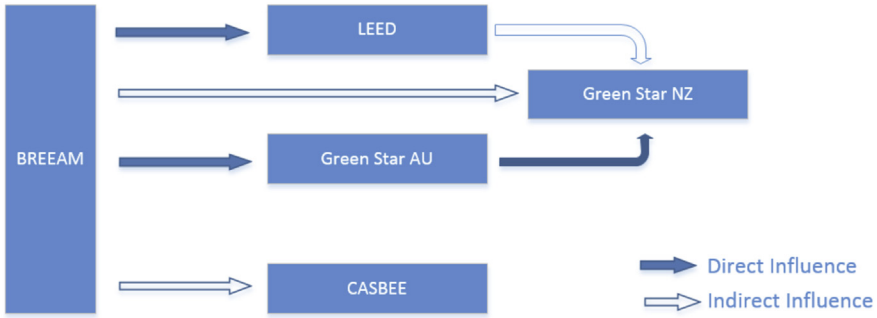


Fig. 2. The relationship among green ratings (adapted from Mao [96]).

territories at present [42]. The square footage of LEED-certified projects has risen dramatically during 2008–2016 (approximately 100%), from around 0.15 billion to over 15 billion square feet [42,96]. Similar to BREEAM, LEED predominantly evaluates environmental factors including *Sustainable Sites, Water Efficiency, Energy and Atmosphere, Material and Resources,* and *Indoor Environment Quality categories*. All of the building's lifecycle could be evaluated based on the criteria from Building Design and Construction, Interior Design and Construction, Building Operations and Maintenance, Neighbourhood Development manuals.

3.3. CASBEE

CASBEE was developed by the collaboration of academia, industry, and the local governments in 2001 in Japan [105,106]. Owing to its limitation to Japanese context, the number of certified buildings is still modest (330 buildings since 2004) [105]. However, it is the rating which evaluates the broadest context (Fig. 3) and started releasing a pilot version for worldwide use in 2015. CASBEE could assess the buildings starting from the design to the renovation with criteria from CASBEE Buildings, CASBEE for Commercial Interiors, and CASBEE for Temporary Construction manuals. While CASBEE for Urban Development and CASBEE for Cities manuals are used as frameworks to evaluate a group of buildings.

3.4. Green Star NZ

The Green Star NZ rating scheme was first launched in 2007 by NZGBC (New Zealand Green Building Council), based on the Australian Green Star [45]. Compared to the rating schemes above, Green Star NZ is the youngest. It is the only one that does not provide a manual to assess the building during its performance phase (Fig. 3). Since it has been in the market for a decade only, the number of certified buildings is still limited. However, it has seen a positive trend (10 times increase since 2009) to reach 125 certifications [107].

3.5. Overview of BREEAM, LEED, CASBEE, and Green Star NZ

BREEAM, LEED, and Green Star NZ were established by non-profit third parties, while the government plays a dominant role in CASBEE besides the industry and academia. Due to the collaborations among various parties, CASBEE could receive the feedbacks and consider them for future updates more frequently, precisely, and thoroughly. This could be a reason why CASBEE is considered as a leader in the assessment of comprehensive area development projects. This includes a group of buildings or a city with the release of *CASBEE Urban Development CASBEE City* (see Fig. 3), even though CASBEE was established after the leading global rating systems BREEAM and LEED a decade and half of a decade, respectively. Green Star NZ is the latest established rating systems compared to BREEAM, LEED, and CASBEE. Consequently, though it could evaluate the majority of the whole life cycle of a project, operation stage assessment is still not covered (see Fig. 3).

The main features of BREEAM, LEED, CASBEE, and Green Star NZ are shown in Table 1. It is clear from the Table that all of these four

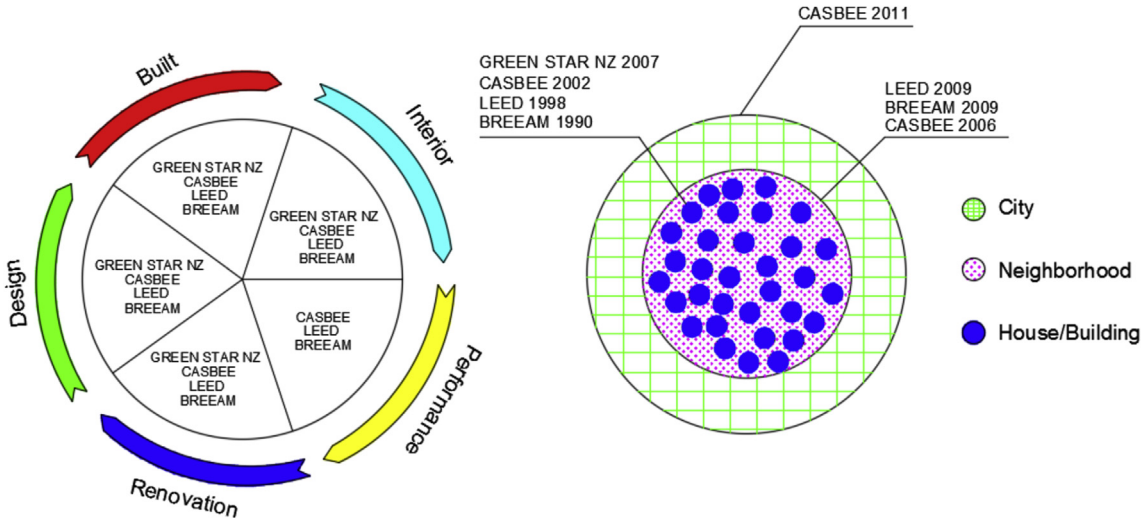


Fig. 3. Overview of green rating tools.

Table 1
Main features of BREEAM, LEED, and Green Star NZ.

	BREEAM	LEED	CASBEE	Green Star NZ
Country	UK	US	Japan	NZ
Organizations	BRE	USGBC	JSBC	NZGBC
Flexibility	77 countries	160 countries	1 country	1 country
First version	1990	1998	2002	2007
Latest version	2016	2013	2015	2016
Main categories	Management Health & Wellbeing Energy Transport Water Material Waste Land Use & Ecology Pollution Innovation	Integrative process Indoor Environment Quality Energy & Atmosphere Location & Transportation Water Efficiency Material & Resources Sustainable Sites Regional Priority Innovation	Indoor Environment Quality of Service On-site Environment Energy Resources & Materials Off-site Environment	Management Indoor Environment Quality Energy Transport Water Material Land Use & Ecology Emissions Innovation
Rating approach	Pre-weighted categories	Additive credits	BEE ranking chart	Pre-weighted categories except for Innovation
Rating level	Pass ≥30 Good ≥45 Very good ≥55 Excellent ≥70 Outstanding ≥85	Certified ≥40 Silver ≥50 Gold ≥60 Platinum ≥80	Poor: BEE <0.5 Fairy Poor: BEE = 0.5–1.0 Good: BEE = 1–1.5 Very good: BEE = 1.5–3; or BEE ≥3 and Q < 50 Excellent: BEE ≥3 and Q ≤ 50	Best practice ≥45 Excellent ≥60 Leadership ≥75
Number of certified buildings	561,600	79,100	541	125

rating schemes just released their latest versions recently. Although the latest version of LEED was released four years ago, it has the new update in 2017 [108]. This proves that all of the rating systems are making efforts to revise and update their criteria more frequently to follow immediately with the rapid development of sustainable construction.

The flexibility or the application of CASBEE and Green Star NZ is still limited; it is suggested that they are only capable of domestic projects leading to the modest certified projects, with 541 for CASBEE and 125 for Green Star NZ. This is because CASBEE and Green Star NZ were just established around a decade ago and they are still at the earlier stages compared to BREEAM and LEED. A pilot version for worldwide use was released in 2015 to make CASBEE more flexible to gain the widespread adoption and the number of registered projects.

BREAM and LEED have a significant number of green certified buildings globally. Despite the different regional characteristics, climate, culture, etc., countries other than the UK and the US could adopt BREAM or LEED. This is because standards used to assess green criteria could be the international standards or local equivalent standards. For example, LEED states that International Society of Arboriculture using ISA standard method or local equivalents could be used to assess *Sensitive Land Protection* in LEED. While BREEAM also allows national or local equivalents to ISO 7730:2005 used to evaluate *Thermal Comfort* sub-category.

BREAM and LEED differ significantly in their flexibility and the number of certified buildings. 561,600 buildings in total were certified by BREEAM, which is seven times higher than those for LEED. Regarding geographic adoption, up to 160 countries and territories have adopted LEED for green project assessment in comparison with 77 countries for BREEAM. This could be explained in three main reasons. Firstly, BREEAM targets the European market where the majority of countries are well-aware of *Sustainability*. Secondly, LEED is considered as a more transparent rating approach for calculating the final results, while BREEAM adopts the pre-weighted categories method which is more complex and stricter. Finally, BREEAM is stricter in its criteria for achieving credits. It sets absolute parameters while relative percentage improvement or reduction targets are employed by LEED. For example, in the sub-category of *Energy*, *Reduction of energy use and carbon emissions*, BREEAM provides guidance in the form of a table for *Energy Performance Ratio for International New Constructions* benchmark scale, in which absolute values are targeted like 0.06 for achieving one credit and 0.9 for achieving 15 credits. While in the sub-category accounting for the highest credits of *Energy and Atmosphere* of LEED, *Optimize energy performance*, a table is created to compare the difference in the percentage of the assessed building energy simulation with the past energy simulation analyses or published data for similar buildings. If the simulation shows that the energy performance improves 6% for new construction, one point will be achieved for a school project, and 16 points will be attained for 42% of the improvement. As a result, BREEAM has many certified projects, but LEED gains global adoption.

Considering the number of main categories of the four rating schemes, it is clear that BREEAM has the highest number of categories (10), which is slightly higher than those of LEED and Green Star NZ with nine categories for each. It is worth noticing that BREEAM, LEED, and Green Star NZ share the same patterns in the characteristics of categories. This is due to the strong influence of BREEAM on LEED and Green Star NZ, as demonstrated in Fig. 2. Although CASBEE is affected by BREEAM, it was established by the cooperation of various parties, including the government, industry, and academia, thereby leading to the difference in the assessed categories constituting only six main categories. These rating schemes have the common categories such as *Energy* and *Material*, even though they are created based on their local contexts. This proves that these same categories are the global concerns and should be considered thoroughly.

In view of the rating approach, LEED adds all credit points to sum up the final grade while BREEAM and Green Star NZ pre-weight the categories before adding them up. Fig. 4 shows the weightings of Green Star NZ and BREEAM.

The weightings for Green Star NZ depend on projects types (Office, Education or Industry). For example, in an *Education* project, *Material* constitutes a higher percentage than the one in an *Office* or an *Industry* project. Likewise, *Indoor Environment Quality* is

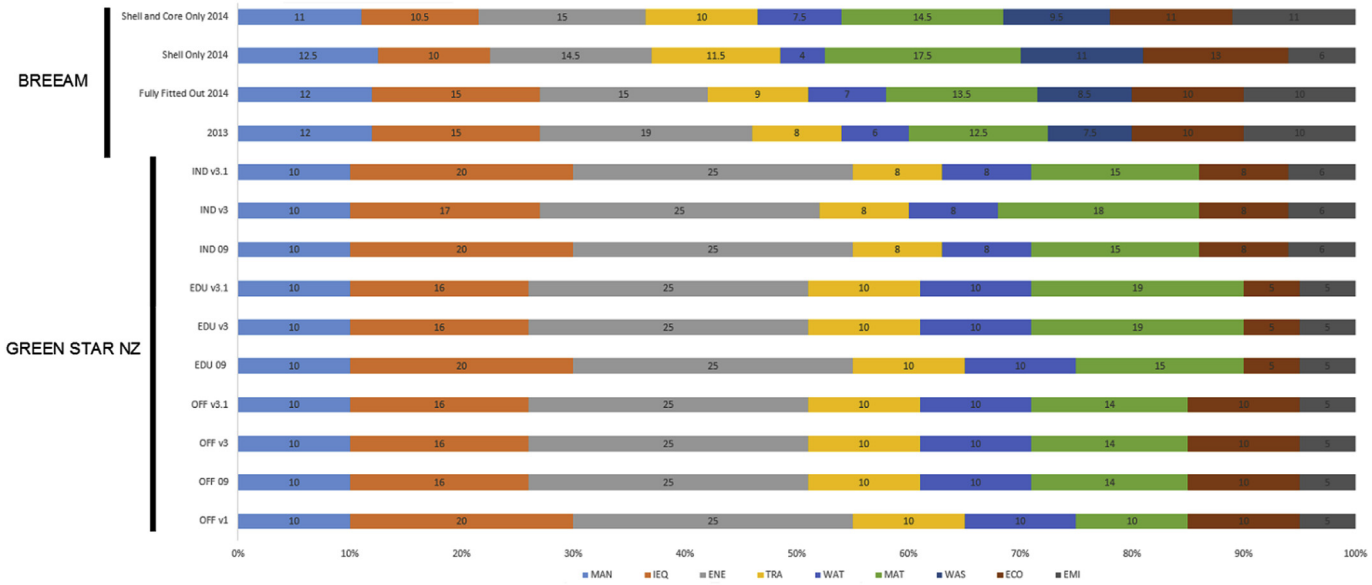


Fig. 4. Green Star NZ's and BREEAM's weightings.

a more significant point of focus in *Industry* projects compared to the others.

BREEAM further categorizes projects into *Shell and core only*, *Shell only*, and *Fully fitted out*. Although BREEAM's and Green Star NZ's weightings are created based on two different local contexts and standards, they have the same common in the weightings of characteristics. It is clear that *Energy* is the most important category in both ratings, accounting for the highest proportion of the weighting scale. In other words, *Energy* is seen as the priority criterion compared to the others. This is understandable due to the excessive energy consumption of the construction industry. According to EIA (Energy Information Administration), buildings constituted almost a third of the global energy consumption [109,110]. Based on the IPCC (Intergovernmental Panel on Climate Change) AR5 (Fifth Assessment Report), buildings consumed 32% of global energy and emission of 19% of energy-related greenhouse gases [111]. Also, buildings were responsible for 40% of the EU energy consumption [112].

Besides the importance of the *Energy* criterion, the weighting scales for *Material* and *Indoor Environment Quality/Health & Wellbeing* also reflect their major priorities in the building evaluation compared to other criteria. The building construction industry is responsible for a substantial proportion of the global raw material consumption exploiting 25% of wood harvest; 40% of stone, sand, and gravel, and 16% of water [113–115], thereby leading to the high weighting scale in *Material*. Whereas *Indoor Environment Quality/Health & Wellbeing* focuses on the wellbeing and health issues of building occupants [116,117]. This is considered as a key role in defining *Green* as: "*providing people with healthy, applicable, efficient space and natural harmonious architecture*" [65–67]. Therefore, the weighting for *Indoor Environment Quality/Health & Wellbeing* is highlighted.

In any manual version of BREEAM or Green Star NZ, *Energy, Material*, and *Indoor Environment Quality/Health & Wellbeing* are prioritized. However, in the later versions, the weighting percentages of *Energy*, and *Indoor Environment Quality/Health & Wellbeing* tend to reduce. In contrast, those of *Material* show an opposite tendency. For example, 20% is the figure of *Indoor Environment Quality* of *Office* version 1, which reduces to 16% in the next three versions, as opposed to *Material* with a growth by 4% in *Office* version 09, version 3, and version 3.1. This could be explained that previous building practices might show a positive trend toward *Energy* and *Indoor Environment Quality/Health & Wellbeing*, while *Material* had not caught much attention yet. These weightings have a strong influence on the final results of BREEAM and Green Star. BREEAM and Green Star follow a similar approach to determine the final results based on "pre-weighted categories". Points will be given for each sub-category which are then summed up for total points of each category. As individual categories have their own weighting scale (e.g. Fig. 4), the total point of each category will be multiplied by the weighting scale which is equivalent to the category before adding up for the final results. In spite of this, LEED uses a simpler method called "additive credits", where all credits are just added up to calculate the final results regardless of the weightings.

In contrast to the rest, the assessment results for CASBEE are calculated in a complex way. It is worth noticing that CASBEE has a different approach to calculating the final results. Instead of separating credits into different green categories such as energy, transportation, etc., CASBEE evaluates two spaces, internal and external, divided by the virtual boundary, see Fig. 5 [105]. In other words, CASBEE evaluates two factors, Q (Built Environment Quality) and L (Built Environment Load). Q is used to assess "improvement in everyday amenity for the building users, within the virtual enclosed space boundary" [105] while L is used to assess "negative aspects of environmental impact that go beyond the virtual enclosed space boundary to the outside (the public property)" [105]. Credits for Q and L are calculated before putting on a BEE (Built Environment Efficiency) chart which is divided according to the line gradient (Fig. 6) for the final results or calculating by the equation BEE = Q/L. An example is displayed in Fig. 5 in which Q = 80 and L = 34. The point (80, 34) is in A gradient translated as a *very good* building in Fig. 5.

A timeline of developments for the discussed four rating systems is displayed in Fig. 7. It is noticeable that, since 2005, they all have been furnished with new tools, most especially BREEAM with almost a new update every year. In contrast to BREEAM and CASBEE, LEED and Green Star NZ have updated their tools synchronously.

Although these four schemes are voluntary tools, they are being used as a mandatory requirement in some regions or for particular

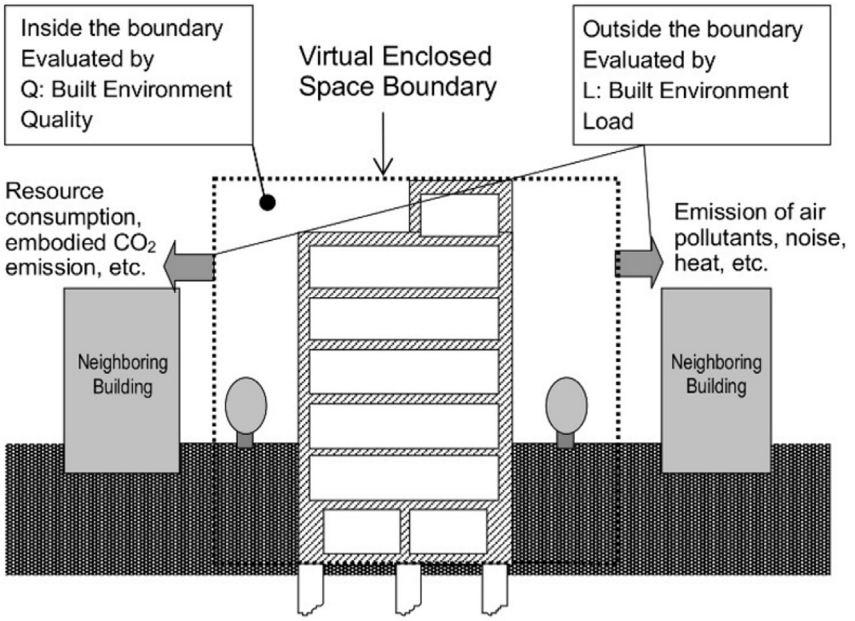


Fig. 5. Built environment quality and built environment load [105].

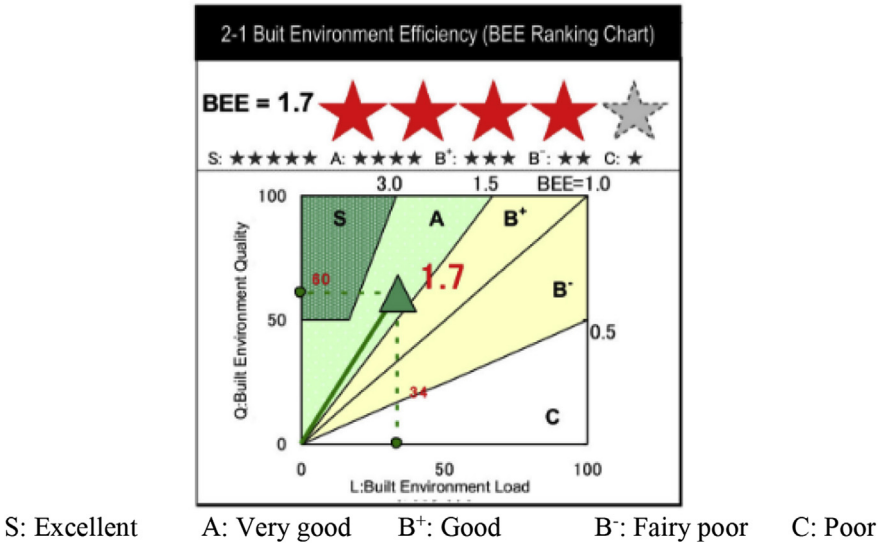


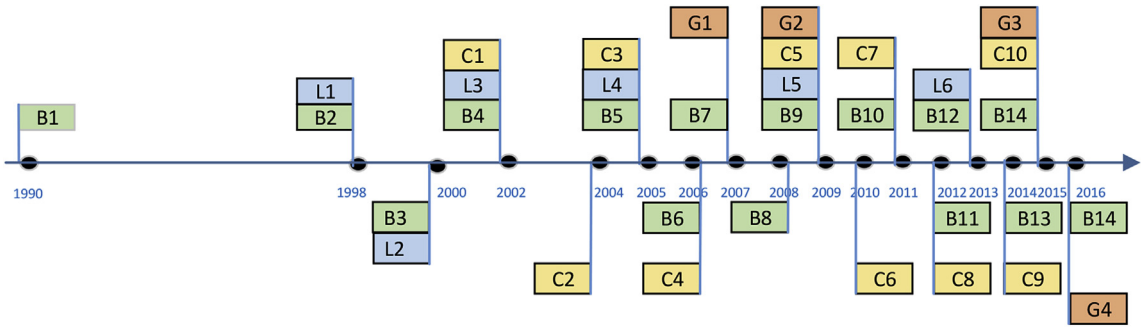
Fig. 6. BEE ranking chart.

purposes. BREEAM assessment is a mandatory requirement to achieve funding from Department of Health and Education in the UK [118]. San Francisco is the first state in the U.S. which required high-rise residential projects to be certified LEED silver by 2010 [119]. CASBEE assessment results have been used as a mandatory for building permits by some local Japanese governments [120], whereas Auckland Council has included requirements for Green Star NZ in the Proposed Unitary Plan [45].

4. Research methodology

This research utilized a two-step approach to review green certifications comprehensively, see Fig. 8.

a. Initially, a systematic desktop search was carried out via major scientific databases namely, Scopus and Web of Science (WOS), to identify the relevant journals for this study. WOS and Scopus are seen as the most widespread databases covering publications in various fields [121]. WOS has a strong coverage with papers published since 1990 and English is the main language in its most journals while a superior number of journals is covered by Scopus [122]. To narrow the selected journals which published many relevant papers, search keywords, including “LEED”, “BREEAM”, CASBEE″, “Green Star NZ”, “Green Building”, and “Sustainable Building” were used under the “article title/abstract/keywords” field for Scopus and “Title” for WOS. Journals publishing the largest number of papers in these fields were identified as Energy and Buildings (E&B), Building and Environment (B&E), Automation in Construction (A&C), Building Research and Information (BR&I), International Journal of Sustainable Building Technology and Urban Development (SBT&UD), Journal of Cleaner Production (CP), Environmental Impact Assessment Review (EIAR), and Renewable and Sustainable Energy Reviews (R&SER). They are also high-ranking



B1	B2	B3	B4	B5	B6	B7
BREEAM 1990	BREEAM 1998	BREEAM 2000	BREEAM 2002	BREEAM 2005	BREEAM 2006	BREEAM 2008
B8	B9	B10	B11	B12	B13	B14
BREEAM 2009	BREEAM 2011	BREEAM 2012	BREEAM 2013	BREEAM 2014	BREEAM 2015	BREEAM 2016

L1	L2	L3	L4	L5	L6
LEED 1.0	LEED 2.1	LEED 2.2	LEED 1.0	LEED 2.1	LEED 2.2

C1	C2	C3
CASBEE for Building (New Construction)	CASBEE for Building (Existing Building)	CASBEE for Building (Renovation)+CASBEE for Heat Island
C4	C5	C6
CASBEE for Urban Development	CASBEE for Detached House (New Construction)+CASBEE for Urban Development	CASBEE for Heat Island+CASBEE School+CASBEE for Building
C7	C8	C9
CASBEE for Detached House (Existing Building)+CASBEE for Cities	CASBEE for Market Promotion+CASBEE for Cities	CASBEE for Detached House+CASBEE for Building+CASBEE for Market Promotion+CASBEE for Urban Development
C10		
CASBEE for Cities		

G1	G2	G3	G4
Green Star v1	Green Star 2009	Green Star v3	Green Star v3.1

Fig. 7. BREEAM, LEED, CASBEE, and Green Star timeline.

journals in the construction field which are ranked by Scimago Journal & Country Rank (http://www.scimagojr.com/), see Table 2. Therefore, they are the mainstreams chosen for reviewing.

Due to the popular use of the chosen search keywords, irrelevant papers are possibly available in the results. Thus, abstracts were read to filter out the irrelevant papers. Unless the papers mainly focused on the green rating systems, they will be excluded. The aim of this first step is to a) observe the development of green rating systems, b) find out how they are popular in the research, c) discover which rating is more globally recognized, d) locate the countries concerning about green building.

b. In a latter step, manuals of BREEAM, LEED, CASBEE, and Green Star NZ were examined to determine their developments, similarities, and differences along with their strengths and weaknesses to determine their support to sustainability. *New Construction* manuals and *Neighbourhood Development* manuals were investigated in this paper. *New Construction* manuals represent for a new individual building assessment guidance. It aims to "*mitigate the life cycle impacts of new buildings on the environment in a robust and cost-effective manner*" [117]. While *Neighbourhood Development* manuals represent for a large-scale development plans guidance. It "*provides a framework to planners, local authorities, developers, and investors through the master planning process, before embarking on procurement, detailed building level design and construction*" [123]. All of the examined manuals are indicated in Table 3.

5. Results and analyses

5.1. Selection of relevant papers

A total of 408 papers were identified in the above-mentioned eight journals; however, 206 papers were delimitated as none of BREEAM, LEED, CASBEE, or Green Star NZ were the main focus. It was discovered that the first set of LEED and BREEAM related papers were published in 1998, see Fig. 9. This field attracted the attention of researchers by the end of the 2000s. The number of published papers increased dramatically from 8 papers in 2010 to 36 papers in 2016.

BR&I contributed the highest number of papers, accounting for 35% of total papers in eight selected journals (Fig. 10). This figure is almost double the total number of papers that E&B released during 1998–2016. A significant increase in a number of published papers was seen in E&B, B&E, and R&SER from 2013 to 2016 (an average of 16 paper each year for these three journals). While BREEAM, LEED, CASBEE, and Green Star NZ have just received attention recently from A&C, CP, SBT&UD, and EIAR. Except BR&I, E&B, and B&E, the rest of the journals published fewer papers, but they all shared a similar pattern, a growth in the number of papers recently.

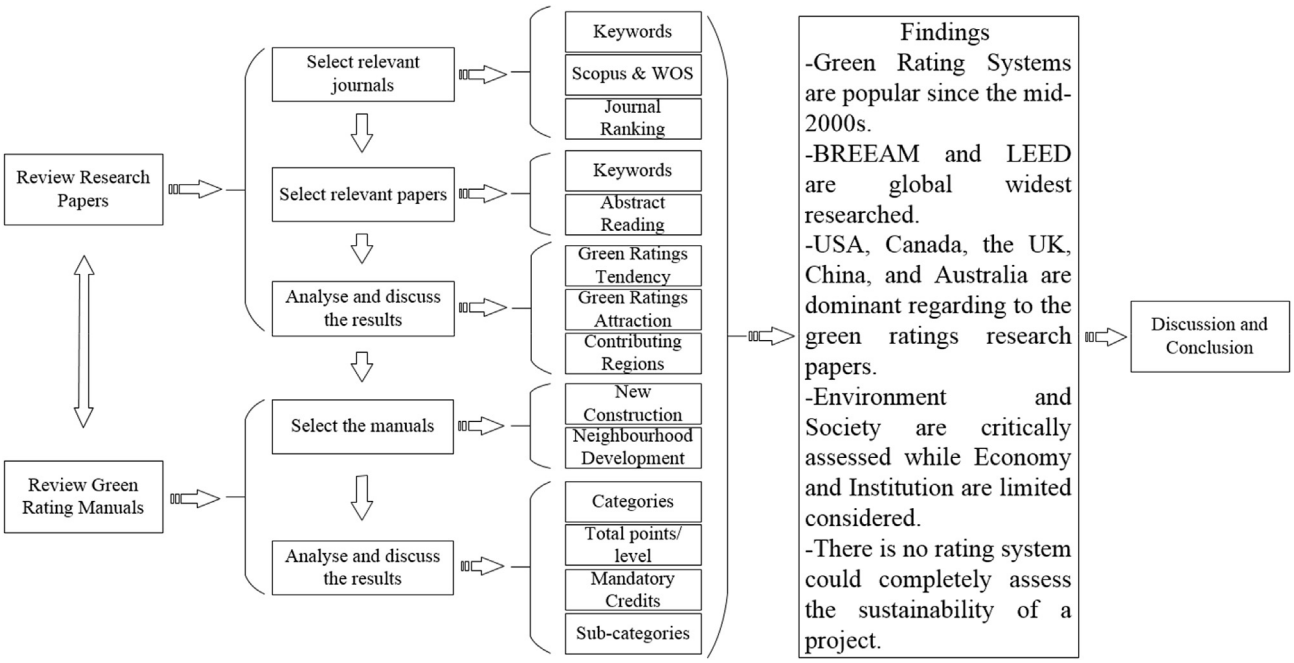


Fig. 8. Methodology steps.

Table 2
Ranking of selected journals.

Areas	Journals	Rank
Building and Construction	B&E	3
	E&B	5
	A&C	13
	BR&I	15
	SBT&UD	115
Renewable Energy, Sustainability and the Environment	CP	21
	R&SER	5
Management, Monitoring, Policy and Law	EIAR	24

Table 3
Selected manuals of BREEAM, LEED, CASBEE, and Green Star NZ.

Manuals	BREEAM	LEED	CASBEE	Green Star NZ
New Construction	2006	2.0	2014	v1
	2008	2.1		2009
	2011	2.2		v3
	2013	v3		v3.1
	2014	v4		
	2016			
Neighbourhood Development	2012	v4	2014	

5.2. Attraction of BREEAM, LEED, CASBEE, and Green Star NZ topics

Despite the use of "BREEAM," "LEED," "CASBEE," and "Green Star NZ" as search keywords, no publications under "Green Star NZ" were found. This is a confirmation that Green Star NZ is still in its earlier stages compared to the rest leading to the academia's neglect. Fig. 11 shows the statistics for the papers related to LEED, BREEAM, and CASBEE. LEED has attracted the most increasing attention with 63% of the total papers (36% more than BREEAM-related publications). In contrast to BREEAM and LEED, with a dramatic increase in the number of papers, the figures for CASBEE have only risen slightly at the beginning of the 2010s.

5.3. Contributing regions

Identifying the contributions of regions/countries on research topics in different fields have been the interest of many researchers [124–126]. Since first authors are seen as the main research contributors in scientific papers, this study examined the research origin of the first authors of the identified papers. 202 papers originated from 30 countries; however, only those countries contributing two or more papers are shown in Fig. 12. It is noted that almost a quarter of papers come from the USA (49 papers). Five leading countries in publications (the USA, Canada, the UK, China, and Australia) have contributed to approximately 70% of the total papers. It is worth noting that these countries are also the origins of widely utilized green rating schemes namely, LEED (USA and Canada), BREEAM (The UK), and Green Star (Australia). Furthermore, developing countries such as Turkey, India, Brazil, and Malaysia, are also aiming for green buildings.

The abovementioned statistics prove that green rating systems are globally well-known and have attracted the attention of many countries including developed and developing ones. Although BREEAM and LEED have been established for a long time, they caught the attention of researchers by the end of the 2000s, especially 2008 in which the number of LEED papers was doubled to reach ten papers per year, while BREEAM's and LEED's figures were also increased.

5.4. Comparison of BREEAM, LEED, CASBEE, and Green Star NZ

5.4.1. New construction manuals

This research compared *New Construction* manuals of the discussed green building rating systems (Fig. 13). Although different terminologies were used to describe BREEAM's, LEED's, CASBEE's, and Green Star's assessment criteria, they generally share common purposes, focusing on environmental concerns, especially in BREEAM, LEED, and Green Star NZ. *Indoor Environment Quality*, *Energy*, and *Material* criteria are all assessed under these four

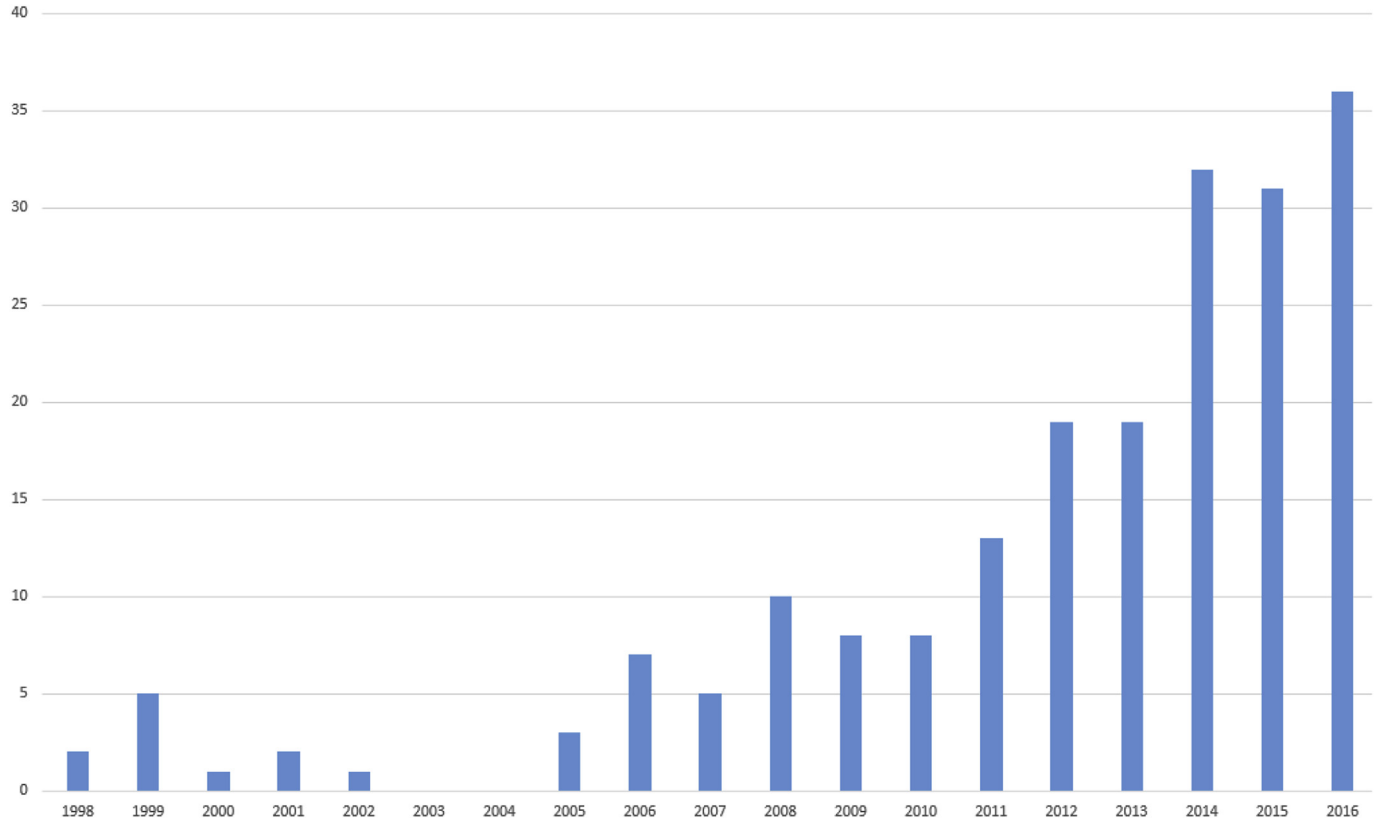


Fig. 9. BREEAM, LEED, CASBEE, and Green Star NZ related papers published from 1998 to 2016.

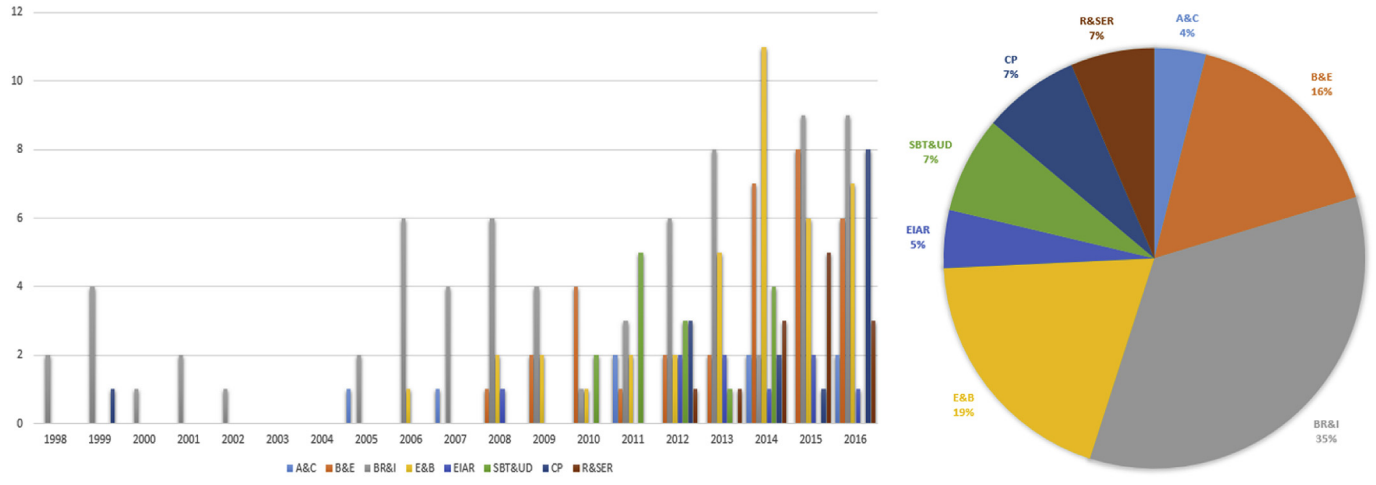


Fig. 10. BREEAM, LEED, CASBEE, and Green Star NZ related papers published in each selected journal.

systems which proves that they are global concerns. Also, the total points for each category of *Indoor Environment Quality*, *Energy*, and *Material* are higher than those of the rest ones. In other words, these categories are the main focus, and they are promoted by international organizations.

Establishing by non-profit organizations and strongly depending on BREEAM, LEED and Green Star NZ have similar categories and total points with BREEAM as opposed to CASBEE. About the total points, BREEAM, LEED, and Green Star NZ have around 150 points on the average. It is worth noticing that the later of the version released, the more total points could be achieved. LEED has the most notable increase in points, from 69 points in version 2 to 145 points in version 4. BREEAM and Green Star NZ followed the same approach in their latest version with their total points increased by over 15 points accumulating to 159 and 153 respectively. This means that the evaluation of the rating systems is gradually comprehensive. Taking BREEAM for example, the total points of *Material* in *International New Construction* 2013 are 11 which then increased by one in *International New Construction* 2016. In the sub-category namely *Responsible sourcing of construction product*, *International New Construction* 2016 assesses not only three credits which are same with 2013 manual but also one more

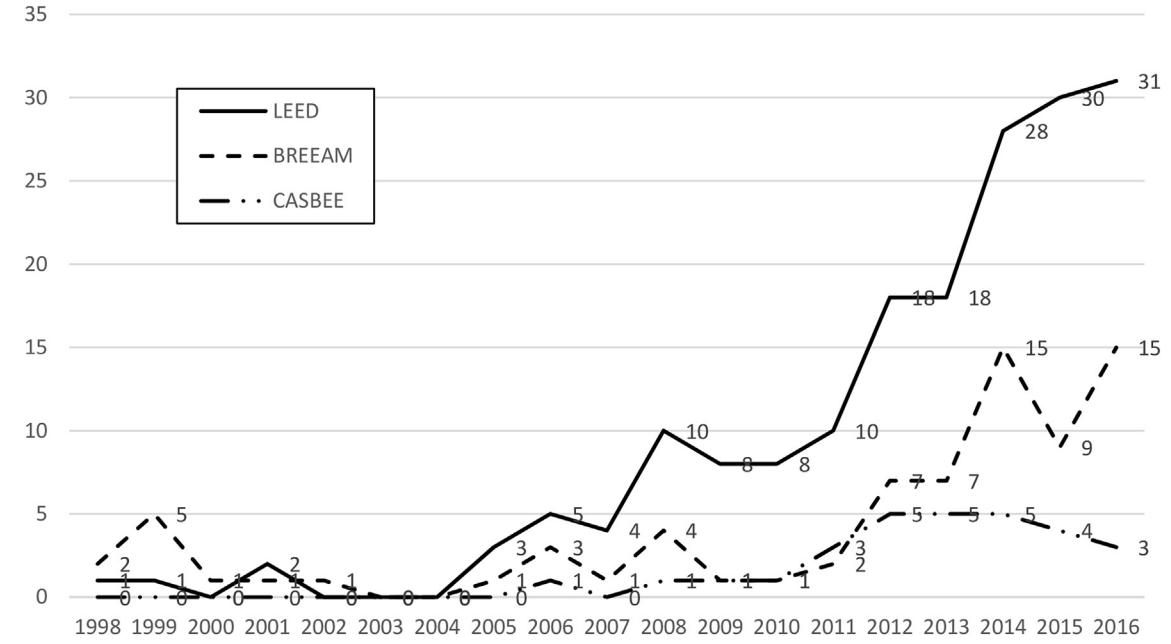


Fig. 11. The proportions of BREEAM, LEED, CASBEE, and Green Star NZ in the research papers.

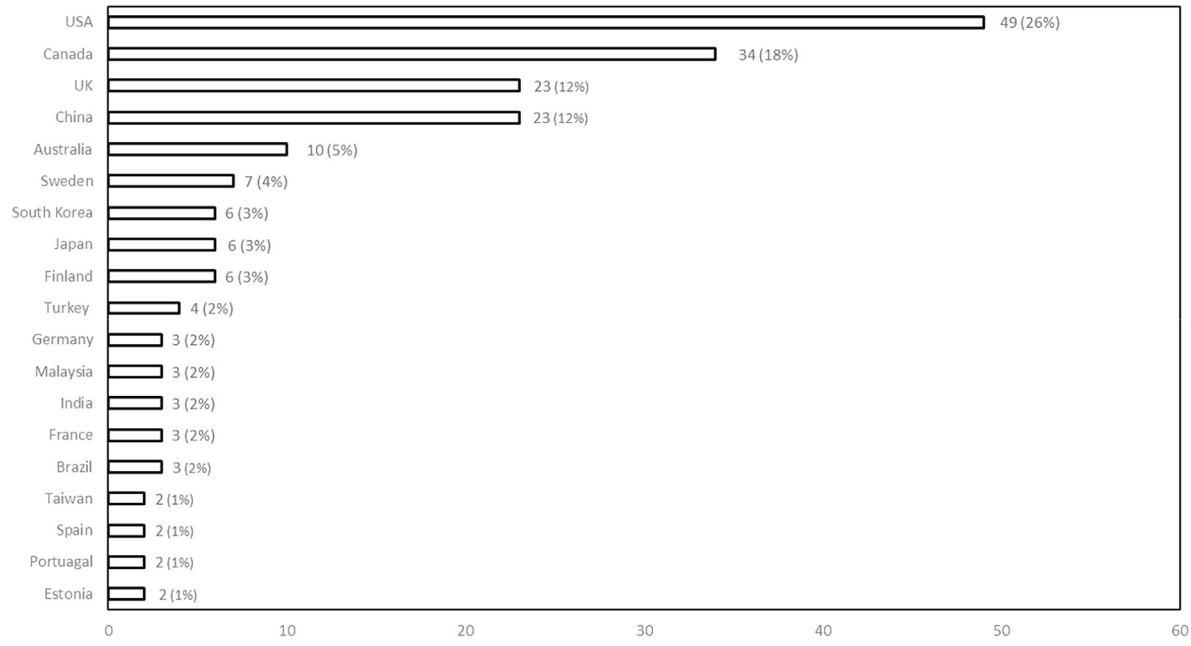


Fig. 12. Research origin of BREEAM, LEED, CASBEE, and Green Star related paper published.

credit for sustainable procurement plan.

While points are gained for the assessment process of BREEAM, LEED, and Green Star NZ, levels are determined for CASBEE evaluation. Point achievement could be seen as a flexible assessment method which does not have any particular maximum points. These points are earned based on the important of the criteria. In *Energy* of Green Star NZ version 3.1, for instance, total points achievement could be 10 for the first sub-category, but it is only one for the second sub-category. It means that the important of the first sub-categories is much higher than that of the second sub-category. This is opposite with CASBEE in which levels are given in a particular range. Five levels are granted from Level 1 to Level 5. Level 1 is earned when the minimum conditions requirement is satisfied, and Level 3 represents the achievement of the ordinary technical and social practices at the time of assessment. Despite the different important of sub-categories, five is the maximum level that each sub-category of CASBEE could be attained. Put differently, the level or the important of each sub-category is equal in CASBEE system in case weighting coefficients are not taken into account, which is totally opposite with BREEAM, LEED, and CASBEE.

In view to the mandatory credits, ensuring a project achieves a certain minimum score in each category, BREEAM, LEED, and Green

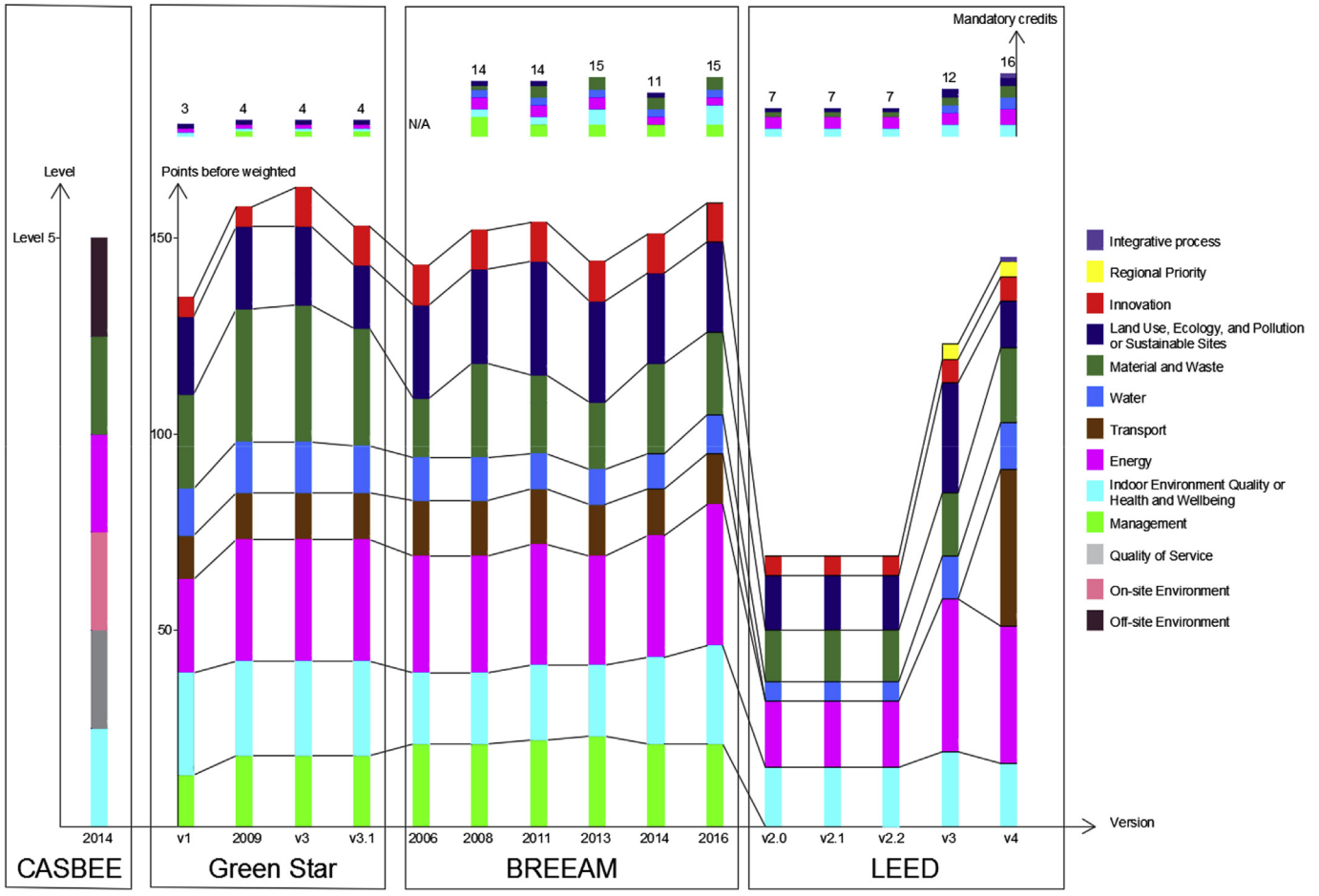


Fig. 13. A comparison of New Construction manuals.

Star NZ increased their credits to prevent *greenwash action*. Greenwash action is defined as "*the use of public relations or marketing in order to promote a misleading perception that a company's policies or products are environmentally friendly*" [127]. In other words, mandatory credits are created to prevent plans achieving green certifications by applying for the least necessary credits. Despite a big difference regarding the total number of mandatory credits in BREEAM and Green Star NZ, they both have the same tendency (a slight increase towards the mandatory credits in their updated versions). BREEAM and LEED share a similar figure in the number of mandatory credits in the latest version while the figure for Green Star NZ is still modest. It is clear from the schemes that *Indoor Environment Quality* and *Energy* are key categories, accounting for a considerable number of points and including mandatory credits in any versions.

Although BREEAM, LEED, and Green Star NZ include a combination of mandatory and non-mandatory credits, they have a different approach for the result calculation. Points could be achieved if a project satisfies the requirement for mandatory credits in BREEAM and Green Star NZ as opposed to LEED when no point is allocated for those credits but it is compulsory to comply with the credits.

This research also investigated the development of sub-categories in these green rating systems (Fig. 14). It is noted that there is a slight rise towards the total number of sub-categories of BREEAM, LEED, and Green Star NZ in the later versions, especially with the release of two new categories in LEED version 4, namely *Integrative Process* and *Location and Transportation*. The categories of these rating systems are analysed in more detail in which more sub-categories are created to assess projects in every angle of the category with the development and the release of new versions of manuals. *Energy* is again emphasized with the rise in sub-categories among BREEAM, LEED, and Green Star NZ. Besides, BREEAM, LEED, and Green Star NZ also have a common increase in the number of *Transport* sub-categories.

It is worth noting that despite the strong dependence on BREEAM, LEED and Green Star NZ have a different way towards the total points and sub-categories breakdown. BREEAM, LEED, and Green Star NZ have a similar total of points, but the total sub-categories of BREEAM are much lower than those of LEED and Green Star NZ, see Fig. 14. In other words, more points can be achieved in each sub-category of BREEAM than those of LEED and Green Star NZ. Furthermore, the total sub-categories of BREEAM except for *Innovation* are fairly equal in each category as opposed to those of LEED and Green Star NZ. *Management* is promoted in New Zealand context while the US focuses on *Sustainable Sites*. However, *Indoor Environment Quality*, *Energy*, and *Material* are emphasized in both LEED and Green Star NZ.

In CASBEE, due to the unavailability of manual in English, only *CASBEE for Building (New Construction)* 2014 is considered. Having the same trend with LEED and Green Star NZ, *Indoor Environment Quality* and *Resources and Material* have the highest number of sub-categories. Besides, *Quality of Service* is taken into account in Japan context. It is worth noticing that CASBEE is the only rating system

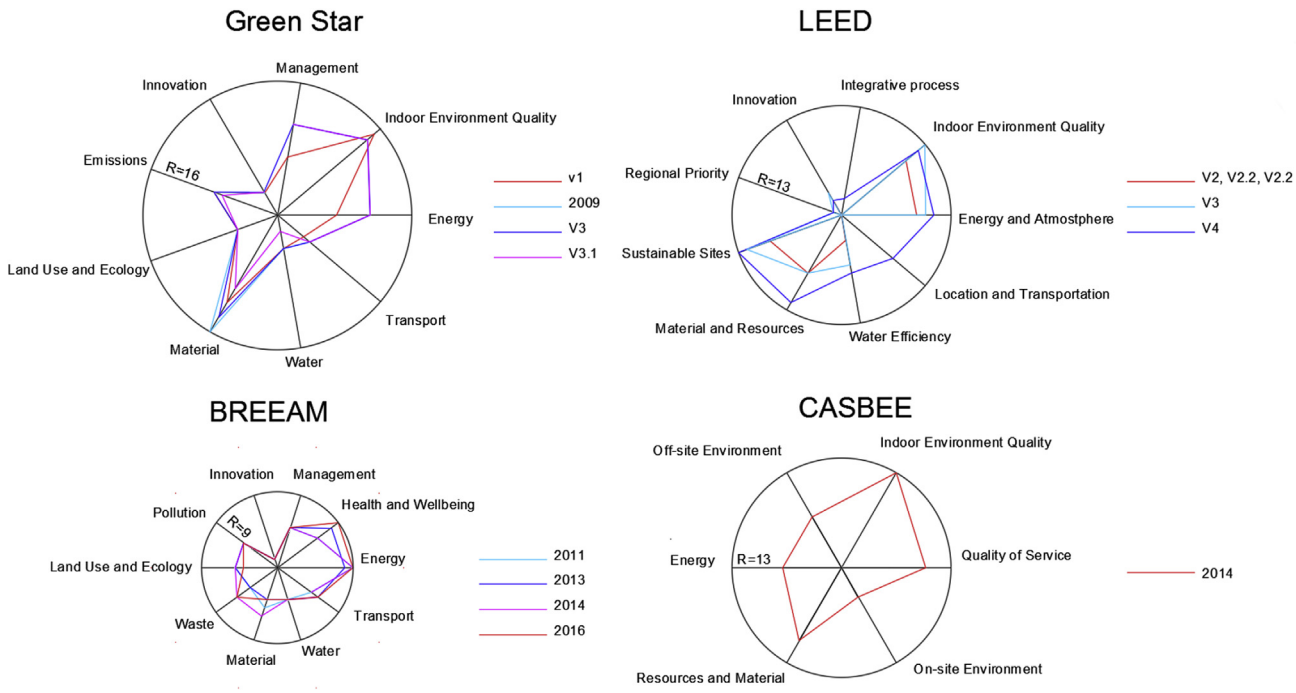


Fig. 14. A comparison of new construction manuals regarding sub-categories.

having *Earthquake Resistance* sub-category to cope with the high frequency of earthquake in Japan.

Despite the influence of BREEAM, these rating systems pay attention to different categories depending on their contexts. However, *Indoor Environment Quality* and *Material* are the key common categories among all with the highest number of sub-categories.

All of the sub-categories were then analysed to categorize them in sustainable pillars including *Environment*, *Society*, *Economy*, and *Institution*, see Table 4. As aforementioned, the number of sub-categories of LEED and Green Star NZ is much higher than those of BREEAM. The figures for LEED and Green Star NZ are exactly the same, with 68 sub-categories, while BREEAM and CASBEE share a common in the total sub-categories, 53 and 51 respectively.

It is clear from Table 4 that some sub-categories fall into *Procedural* in which none of *Environmental, Social, Economic*, or *Institutional* factors is assessed. For example, some points can be achieved if a project proves that accredited professional people participate in the project for Green Star, or the integrated design process is recognized and encouraged for BREEAM and LEED. While CASBEE rewards levels for sufficient maintenance plans. Approximately 15% of total sub-categories of Green Star NZ are divided into *Procedural* compared to BREEAM, LEED, and CASBEE with a relatively low percentage. In other words, sub-categories of BREEAM, LEED, and CASBEE are more sufficiency regarding the green or sustainable assessment in which more percentage of total sub-categories is used to assess sustainable pillars.

Environment is the key factor on which all of the rating systems

Table 4
A comparison regarding sustainable aspects by sub-categories.

Sub-categories	BREEAM (53)	LEED (68)	CASBEE (51)	Green Star NZ(68)	Average
Procedural	Management ≈ 4 **Total ≈ 7.5%**	Integrative Process = 2 **Total ≈ 2.9%**	Quality of Service ≈ 3 **Total ≈ 5.9%**	Management ≈ 10 **Total ≈ 14.7%**	**7.8%**
Environment	Health &Wellbeing ≈ 7 Energy ≈ 9 Transport ≈ 3 Water ≈ 4 Material ≈ 4 Waste ≈ 6 Land Use & Ecology ≈ 4 Pollution ≈ 5 **Total ≈ 79.3%**	Location & Transportation ≈ 3 Sustainable Sites ≈ 13 Water Efficiency ≈ 7 Energy & Atmosphere ≈ 11 Material & Resources ≈ 10 Indoor Environment Quality ≈ 12 **Total ≈ 82.4%**	Indoor Environment ≈ 13 Energy ≈ 7 Resources & Material ≈ 10 Off-site Environment ≈ 7 Quality of Service ≈ 6 **Total ≈ 84.3%**	Management ≈ 1 Indoor Environment Quality ≈ 13 Energy ≈ 11 Transport ≈ 4 Water ≈ 2 Material ≈ 9 Land Use & Ecology ≈ 5 Emissions ≈ 6 **Total ≈ 75.0%**	**80.2%**
Society	Health & Wellbeing ≈ 2 Transport ≈ 3 **Total ≈ 9.4%**	Location & Transportation ≈ 5 Material & Resources ≈ 2 Regional Priority ≈ 1 **Total ≈ 11.8%**	Quality of Service ≈ 1 On-site Environment ≈ 4 **Total ≈ 9.8%**	Indoor Environment Quality ≈ 1 Transport ≈ 1 Material ≈ 1 Emissions ≈ 1 **Total ≈ 5.9%**	**9.2%**
Economy	Management ≈ 1 **Total ≈ 1.9%**	**Total = 0.0%**	**Total = 0.0%**	**Total = 0.0%**	**0.5%**
Extra	Innovation = 1 **Total = 1.9%**	Innovation = 2 **Total = 2.9%**	**Total = 0.0%**	Innovation = 3 **Total = 4.4%**	**2.3%**

focus. More than 75% of total sub-categories are adopted in any rating systems, around 80% on average, to evaluate *Environmental* factor. *Energy, Material*, and *Indoor Environment Quality/Health & Wellbeing;* which are dominant in weighting coefficients, the number of points, and the number of sub-categories; are all available under *Environment*. This confirms that *Environment* is the main focus in the *New Construction* manuals.

Although *Society* has caught attention recently, the number of sub-categories for *Social* assessment is still modest, with around five sub-categories on the average, accounting for approximately 9% of total sub-categories, for these four rating systems. BREEAM is the only rating scheme considering economic aspects (2% = one sub-category). Except for CASBEE, the rest three ratings have extra sub-categories for *Innovation* in which more points could be achieved. These sub-categories have not been classified in any sustainable pillars. *Innovation* points could be gained once a project achieves exceptional or innovative performances in which these performances are not included or go beyond the requirement of the credit criteria. Therefore, depending on the project stakeholders, these sub-categories could be categorized as *Environmental, Social, Economic*, or *Institutional* factors. *Innovation* could improve the flexibility and capability of rating systems.

It is noticeable that all the rating systems except for Green Star NZ have similar figures for *Procedural, Environment*, and *Society* despite the different local contexts which rating systems are implemented. Besides, all these four schemes have failed to assess the *Institutional* pillar while *Economy* is only mildly evaluated in BREEAM. It could be validated that *New Construction* tools could be only adopted to examine how green buildings are and they could not be used for sustainable assessment.

5.4.2. Neighbourhood Development/Communities/Urban Development manuals

Difference with *New Construction* tool assessing individual buildings, *Neighbourhood Development/Communities/Urban Development* tools have been released to evaluate how sustainable a comprehensive area development project will be. Although CASBEE was established much later than BREEAM and LEED, it is the first organization releasing this type of tool in 2006 compared to the ones of BREEAM and LEED in 2009 (see Fig. 3). Till now, Green Star NZ is still the only system which does not have a tool to evaluate a group of buildings.

A breakdown of sub-categories regarding the sustainable pillars was examined, see Table 5. LEED has the widest scope regarding the *Neighbourhood Development* with 56 sub-categories, which is 15 and 27 higher than those of BREEAM and CASBEE respectively. Compared to *New Construction*, none of the sub-categories falls into *Procedure* which is unnecessary for sustainable assessment. As shown in the names of the tools, *Neighbourhood Development/Communities/Urban Development, Society* is the most promoted pillar here. Over 60% of total sub-categories have been used to assess social factors in BREEAM and LEED, which doubles the figure for CASBEE.

Although *Environment* is not the main focus in these tools, a considerable proportion of sub-categories has been still used to assess the *Environmental* factors. LEED and CASBEE share the same figure with almost a third of total sub-categories, which around 10% higher than that of BREEAM. *Urban Development* marks the impressive growth of CASBEE in *Economic* assessment. The *Economy* of a project could be assessed by over a third of sub-categories of CASBEE, while the figures for both BREEAM and LEED are still very modest. It is noticeable that CASBEE is almost equal not only in the level or the important of each sub-category but also equal in the proportions of total-sub-categories for *Environmental, Social*, and *Economic* assessment. CASBEE could be seen as a balanced tool in *Urban Development* assessment. BREEAM is one more time a leader of sustainable assessment when it is the only tool could measure four pillars of sustainability, with few aspects of the *Institutional* pillar.

In comparison with *New Construction*, these tools have evolved considerably to assess *Social* and *Economic* factors, 52.63% and 15.13% of total sub-categories respectively; however, it is still far ahead for these tools to be seen as sustainable assessment ones. In four pillars, only *Environment* and *Society* are paid much attention, contributing around 80% of total sub-categories, while little emphasis is placed for *Economy* and *Institution*. Limited knowledge or the vague of the sustainable concept leads to the uncertainty of the parameters in sustainable assessment could be a reason for this unbalanced focus. Compared to the rest sustainable pillars, *Environment* has been defined and analysed for a long time, thereby all of the rating tools could assess the *Environmental* factors properly. *Society*, the second appeared pillar, is known and analysed soon after the *Environment*. This could be explained why *Society* is then promoted in *Neighbourhood Development/Communities/Urban Development* tools while *Economy* and *Institution* have still on the way of the development.

6. Discussion

The comprehensive review of relevant papers provides strong

Table 5
A comparison regarding sustainable aspects by sub-categories in neighbourhood development manuals.

Sub-categories	BREEAM (41)	LEED (56)	CASBEE (29)	Average
Environment	Resources & Energy ≈ 5 Land Use & Ecology ≈ 3 **Total ≈ 19.5%**	Neighbourhood Pattern & Design ≈ 1 Green Infrastructure & Buildings ≈ 16 **Total ≈ 30.4%**	Resource ≈ 4 Nature ≈ 4 Artifact ≈ 1 **Total ≈ 31.0%**	**26.97%**
Society	Social & Economic Wellbeing ≈ 14 Resources & Energy ≈ 2 Land Use & Ecology ≈ 3 Transport and Movement ≈ 6 **Total ≈ 61.0%**	Smart Location & Linkage ≈ 14 Neighbourhood Pattern & Design ≈ 15 Green Infrastructure & Buildings ≈ 5 Regional Priority ≈ 1 **Total ≈ 62.4%**	Impartiality/Fairness ≈ 2 Safety/Security ≈ 4 Amenity ≈ 4 **Total ≈ 34.5%**	**52.63%**
Economy	Social and Economic Wellbeing ≈ 3 **Total ≈ 7.3%**	Neighbourhood Pattern & Design ≈ 2 **Total ≈ 3.6%**	Traffic/Urban Structure ≈ 4 Growth Potential ≈ 3 Energy System ≈ 3 **Total ≈ 34.5%**	**15.13%**
Institution	Governance ≈ 4 **Total ≈ 9.8%**	**Total =0.0%**	**Total =0.0%**	**3.27%**
Extra	Innovation = 1 **Total ≈ 2.4%**	Innovation = 2 **Total ≈ 3.6%**	**Total =0.0%**	**2%**

evidence of the essence and the recognition of green rating systems to the construction industry recently. BREEAM, LEED, CASBEE, and Green Star NZ have been researched in 202 papers in eight journals during 1998–2016, and a dramatic increase in the number of papers since the mid-2000s is noted. It is consistent with Eichholtz [128]'s statement in which the popular of green building has greatly increased since 2000. The review confirms that BREEAM and LEED are dominant regarding the breadth and a total number of papers published compared to CASBEE and Green Star NZ during the research period. This could indicate that BREEAM and LEED are most widespread globally and more commonly used in comparison to the other rating tools [129]. Also, the attraction of green rating systems depends on their marketing as well as their transparency, which was proved by the case of BREEM and LEED [130]. BREEAM focuses on the European market in which the *Green/Sustainability* definition seems to be more well-aware of than the other markets, leading to the high number of certified projects. While LEED is more transparency and easier to be certified than BREEAM which promotes the popular of LEED globally based on the adoption of countries.

To follow the sustainable trend of building development, *New Construction* is continuously updated. More points, sub-categories, and categories are added in the later versions to assess a project more comprehensively, especially LEED with a double increase toward the total points and an available of two more categories in the version 4. In *New Construction*, all assessment ratings concentrated mainly on *Environment* while *Society* receives less attention. Besides, only BREEAM has one sub-category considering *Economic* aspects. Therefore, *New Construction* could be considered as a green rating system rather than a sustainable rating system.

Due to the need to address issues in local contexts of individual countries or regions, different rating systems have a different emphasis. The categories of LEED and Green Star NZ are fundamentally similar with BREEAM while CASBEE could be seen as an independent scheme in which their categories and sub-categories are set up based on Japan's distinctive identity even though LEED, CASBEE, and Green Star NZ are all influenced by BREEAM. However, *Indoor Environment Quality/Health & Wellbeing*, *Energy*, and *Material* are the core categories in *New Construction* manuals in any ratings, accounting for major points, mandatory credits, weightings, and sub-categories. In other words, *Indoor Environment Quality/Health & Wellbeing*, *Energy*, and *Material* are widely concerned and international promoted. These are followed by *Transport, Land Use* and *Ecology*.

Results in *Neighbourhood Development/Communities/Urban Development* indicate that although these tools have developed significantly, their sub-categories have failed to address all aspects of *Economy* and *Institutional* sustainability. While *Environment* and *Social* are placed great importance, only few sub-categories are established to measure the *Economy* of a project and solely BREEAM takes *Institutional* dimension into account. Despite dramatic evolving, *Neighbourhood Development/Communities/Urban Development* could only assess two over four dimensions of sustainability. This could be explained that *Environmental* and *Social* dimensions were critically analysed leading to the details of their factors in which these could be measured and evaluated. While it is still struggling with precisely defining *Economic* and *Institutional* pillars to have their factors fully assessed.

Greenwashing could be an issue when gaining enough points for certification without addressing pertinent issues related to the sustainability is the main focus of building owners [131,132]. To prevent greenwashing action, mandatory credits have been introduced. Except for CASBEE which does not use mandatory credits, BREEAM, LEED, and Green Star NZ have seen an increase in the total of those credits. However, LEED is the only rating system which does not have reward points for mandatory credits. LEED should be considered as a reference for the other rating schemes to follow in mandatory credits. This is because it emphasizes the role of these credits are not negotiable and have to be satisfied even though achieving these credits could not positively affect the final result.

After reviewing these four rating systems, their strengths and weaknesses are summarized in Table 6. It is clear that each rating system has its own strengths and weaknesses. LEED is popular with the global adoption while CASBEE is well-known with its balanced tools. It could be seen that BREEAM is currently leading in sustainable assessment when it could assess more aspects in both *New Construction* and *Communities.* Otherwise, Green Star NZ should make more considerable efforts to have its tools more comprehensive in the sustainable assessment. The process of attaining green certifications or implementing environmental activities are considered as time-consuming and high spending [133–138]. Therefore, entirely transparent processes with detailed guidance in manuals along with case studies confirming that green certified buildings are much less costly in the long term than non-certified

Table 6
Strengths and Weaknesses of rating systems (adapted from manuals in Table 3).

		BREEAM	LEED	CASBEE	Green Star NZ
Establishment		Only non-profit third party	Only non-profit third party	Corporations of government, industry, and academia.	Only non-profit third party
Market Penetration		Popular use in the European market	Global adoption	Only in Japan (published a pilot version for international use)	Only in NZ
Building's lifecycle assessment		Design, Built, Operation and Refurbishment	Design, Built, Operation and Refurbishment	Design, Built, Operation and Refurbishment	Design, Built, and Refurbishment
Large-scale projects manual		Communities manual	Neighbourhood Development manual	Urban Development manual, and City manual	None
Attraction		Global researchers and organizations	Global researchers and organizations	Limit	None
Results calculation		Moderation	Transparency	Complex	Moderation
Mandatory credits		Use	Use	None	Limit
New Construction manual	Environment	Sufficient assessment	Sufficient assessment	Sufficient assessment	Sufficient assessment
	Society	Limited assessment	Limited assessment	Limited assessment	Limited assessment
	Economy	Limited assessment	None	None	None
	Institution	None	None	None	None
Communities/ Neighbourhood Development/ Urban Development	Environment	Sufficient assessment	Sufficient assessment	Sufficient assessment	None
	Society	Sufficient assessment	Sufficient assessment	Sufficient assessment	None
	Economy	Limited assessment	Limited assessment	Sufficient assessment	None
	Institution	Limited assessment	None	None	None

ones should be provided.

7. Conclusion

All of the building rating systems have evolved over the years and have been updated to become more demanding in line with technological advances. This paper aims to develop a systematic review of the development of green rating systems focusing on four well-known rating systems, namely BREEAM, LEED, CASBEE, and Green Star NZ to 1) discover how interest and research in green rating systems have developed; 2) identify the similarity, difference, strength and weakness of green rating systems; 3) examine whether they fully assess the projects in all aspects of sustainability.

The results indicate that green rating systems have become the focus point of various researchers recently. Since 1998, 408 papers mentioned BREEAM, LEED, or CASBEE in E&B, B&E, A&C, BR&I, SBT&UD, CP, EIAR, R&SER while 202 of these papers focused on these ratings with a more in-depth approach. During the research period of 1998–2016, the number of green rating related papers rises sharply from only 2 to 36 on an annual basis. BREEAM is the first released green rating system in the world which certified approximately 560,000 buildings, but LEED is seen as the most flexible tool used in 160 countries and territories. In addition, there are a significantly higher number of papers discussing LEED compared to BREEAM concerning the eight main journal sources for this research since 1998. While the CASBEE and Green Star NZ related research papers are still limited. Green or sustainable building assessment is a global concern in both developed and developing countries. USA, Canada, the UK, China, and Australia have contributed up to approximately 70% of the total papers while Turkey, India, Brazil, and Malaysia are prominently considering green rating systems in their research schemes.

The similarity, difference, strength, and weakness of green rating systems were also identified based on the research manuals. The total categories, sub-categories, points, and mandatory credits tend to increase and more comprehensive in order to completely assess the sustainability of a project. LEED is the particular scheme in which the total points and mandatory credits were double in the version 4 since the version 2 besides the addition of two more categories. BREEAM is considered as the strongest rating system in which *Environment* and *Society* are carefully assessed along with the consideration in *Economy* and *Institution*. The weakest system could be Green Star NZ when it could only focus on one pillar of the sustainability, *Environment*. While *Society* is critically evaluated by LEED; and CASBEE is a well-balanced tool in *Environment, Society*, and *Economy* assessment. However, no rating scheme could assess a project in all aspects of sustainability.

This paper could be valuable for both green practitioners and researchers to have an overall understanding of BREEAM, LEED, CASBEE and Green Star NZ. Categories, points, and mandatory credits were discussed in details to pinpoint the current status/tendency of the green building rating systems. In addition, strengths and weaknesses of each rating system were also analysed. Besides, the difference between *New Construction* and *Neighbourhood Development/Communities/Urban Development* were also examined to identify which sustainable pillars could be assessed by these tools.

It is recommended to include *Economic* and *Institutional* factors as supplementary assessment criteria and manuals for green building rating systems for a more comprehensive and through review of the project. Further research is needed to validate the impacts of adding *Economic* and *Institutional* factors to current green building certification systems.

To provide a better background knowledge of green rating systems, *Interior Design, Building Operation* and other manuals should be examined, but this research was only considered two main manuals, *New Construction* and *Neighbourhood Development* manuals. In addition, only recently CASBEE's manuals were analysed because the previous ones are not in English. Furthermore, the examination in the four selected rating schemes may not reflect the overall trend of hundreds of schemes worldwide. These could be the limitations of this research.

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