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An Analysis of the Most Adopted Rating Systems for Assessing the Environmental Impact of Buildings

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Abstract: Rating systems for assessing the environmental impact of buildings are technical instruments that aim to evaluate the environmental impact of buildings and construction projects. In some cases, these rating systems can also cover urban-scale projects, community projects, and infrastructures. These schemes are designed to assist project management in making the projects more sustainable by providing frameworks with precise criteria for assessing the various aspects of a building's environmental impact. Given the growing interest in sustainable development worldwide, many rating systems for assessing the environmental impact of buildings have been established in recent years, each one with its peculiarities and fields of applicability. The present work is motivated by an interest in emphasizing such differences to better understand these rating systems and extract the main implications to building design. It also attempts to summarize in a user-friendly form the vast and fragmented assortment of information that is available today. The analysis focuses on the six main rating systems: the Building Research Establishment Environmental Assessment Methodology (BREEAM), the Comprehensive Assessment System for Built Environment Efficiency (CASBEE), the *Deutsche Gesellschaft für Nachhaltiges Bauen* (DGNB), the *Haute Qualité Environnementale* (HQE^{TM}), the Leadership in Energy and Environmental Design (LEED), and the Sustainable Building Tool (SBTool).

Keywords: rating systems; building environmental impact; sustainability; BREEAM; CASBEE; DGNB; HQE; LEED; SBTool

1. Introduction

Rachel Carson's book *Silent Spring* (1962), in which she describes the powerful—and often negative—effect humans have on the natural world, gave birth to the modern environmental movement. Initially, the environmental movement was mostly concerned about toxics such as Dichlorodiphenyltrichloroethane (DDT) and other pesticides. Later, the focus shifted to air pollution, such as acid rain, and there is a current focus on the continued global warming and the accumulation of plastics in the oceans. Awareness of the damage being done to the planet has gradually pushed scientists and policy-makers to struggle with the problem of climate change (among other issues) because of anthropic activity. In this regard, the concepts of sustainable development [1] and sustainability, which are closely related to each other, were introduced into public discussion. However, the definition of sustainable development introduced by the Brundtland Report has been criticized for its focus on continued economic growth in a limited world [2,3], in opposition to the theories on *limits to growth* [4,5]. So far, economic growth has been almost directly correlated with the exergy from fossil fuel combustion [6]. Thus, continued industrialization and technological development, conceived as human triumph over nature [7], has led to a rapid overexploitation of natural resources without ensuring a maximum long-term use. Continued economic growth has led to an overuse of environmental resources. Global warming is an example of the overuse of waste sinks, as greenhouse gases are wastes (i.e., an unwanted product from the burning of fossil fuel) emitted into the atmosphere. In this context, it is of paramount importance that all economic sectors contribute to ensuring a long-term ecological balance that fosters an exploitation of the natural resources aligned with the restoring capacity of the planet. This is the foundation of sustainability that, in technical terms, is commonly examined through three dimensions: the effect of a phenomenon or system on society (often referred to as *social sustainability*), its impact on the environment (often referred to as *environmental sustainability*), and its economic implications (often referred to as *economic sustainability*). This threefold depiction (Figure 1) is called the triple bottom line (TBL) of sustainability; it was first introduced by Elkington [8] in 1994 and is still used nowadays.

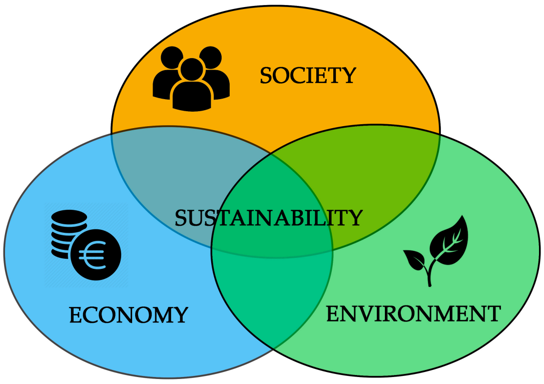

Figure 1. Triple bottom line of sustainabiliy. Source: [8].

The aim of the TBL is to consider the impact of resource consumption and the value creation in terms of integration among the three dimensions, assuming that each of them is equally important.

According to the Western Australia Council of Social Services [9], *social sustainability* is the capacity to provide a good quality of life by creating healthy and livable communities based on equity, diversity, connectivity, and democracy. This *moral capital* requires the maintenance and the replenishment of shared values and equal rights. Human capital is accepted today as part of economic development [10]. In this regard, it is necessary to define *economic sustainability* as the optimal employment of existing resources, so that a responsible and beneficial balance can be achieved over the long-term to reach the preservation of the capital. Economic sustainability concerns the real economic impact that a society has on its economic environment. The final definition to complete the triad of the TBL is *environmental sustainability*. It is defined as the capacity to use natural resources without exceeding their regenerative capacity and protecting the "natural capital" to prevent harm to humans and the environment. This means constraining the scale of the human economic system within the biophysical limits of the overall ecosystem on which it depends; therefore, environmental sustainability is inherently linked with the concepts of sustainable production and sustainable consumption [9].

Going into the details of the TBL framework, and based on the three sustainability dimensions, a wide variety of rating systems have been developed for assessing the environmental performance of buildings, and these are currently available on the market.

These tools have been proposed by different research institutions and have been shaped to reflect specific needs. Crawley and Aho [11] provided the first comparison between some of the major environmental assessment methods in 1999. They focused on the building sector and assessed the environmental sustainability specifically by comparing the scopes of four schemes and identifying general trends. Later, a milestone in categorizing tools was carried out in 2008 by Haapio and Viitaniemi [12] in which the schemes are classified by building types, users, phase of the life cycle, databases accessed, and the form in which the results are presented, such as graphs, tables, grades, certificates, and reports. In the same year, Ding [13] proposed an overview of the role of the building assessment methods in developing a sustainability index that might be used for assessing projects and then for setting out a conceptual framework for appraising projects. Recent works have been published by Berardi [14,15], Todd, et al. [16], Abdalla, et al. [17], and provide a discussion on the topic from different perspectives.

The scope of this paper is to collect the widest range of available information from technical manuals and official websites and via direct relationships with agents on the boards of companies or institutions that created these assessment tools. The main contributions offered by this paper are the analysis of many rating systems for buildings that were collected from different sources, the reconstruction of their chronological evolution and geographical distribution worldwide, and the thorough comparison and analysis of the six most studied and adopted rating systems. Moreover, the scoring mechanisms of these six rating systems are presented.

The paper is divided into six sections. The first describes the concepts underlying the environmental assessment schemes. The second section summarizes the two main approaches for assessing building sustainability performance: rating systems and life cycle assessment. Appendix A collects a large number of schemes and tools and provides information about their year of introduction, promoting countries, and owners/administrators. The list of rating systems listed in Appendix A may not be exhaustive, although a wide range is included. The material and methods adopted to develop this paper are presented in Section 3. After the establishment of four selection criteria, six rating systems were selected and are presented in detail in Section 4. Section 5 is dedicated to the analysis and comparison of the six selected schemes based on several criteria such as project type, building type, life cycle phase, and scopes, arranged considering all the aspects involved in environmental performance evaluation. A summary of the primary contributions of this paper is presented in the last section.

2. Overview of Environmental Assessment Schemes for Buildings

During the last 20 years, there have been significant developments in the investigation of the impact of buildings on the environment. The common tendency has been to establish an objective and comprehensive methodology for assessing a broad range of environmental impacts caused by a building or even a group of buildings. The purpose of these schemes is to measure the environmental sustainability of a built environment in a consistent and comparable manner, with respect to pre-established standards, guidelines, factors, or criteria [18]. The two main approaches that have been used to design environmental assessment schemes for buildings are life cycle assessment (LCA) and building assessment methods or rating systems. In some applications, both of these approaches were combined [11,16].

In this paper, we only focus on the analysis of rating systems and do not carry out an in-depth investigation of LCA tools that are mostly designed to estimate the embodied energy or equivalent emissions related to materials and products. Brief information on both rating systems and LCA tools are presented in the subsequent two sections.

2.1. Life Cycle Assessment

The life cycle assessment is a method for examining the environmental impact of a material, product, or process throughout its whole life cycle [19,20]. This procedure of assessment—in some cases considered more objective than others—appraises in a quantitative way all the exchange flows between the products and the environment in all the transformation processes involved. It can be applied to a wide spectrum of fields, including the building industry.

LCA is distinguishable in two approaches that are called *attributional LCA* and *consequential LCA*. *Attributional LCA* focuses on the analysis of the physical environmental impact from a life cycle perspective, while *consequential LCA* analyzes how this environmental impact will change in response to possible decisions [20]. In both approaches, LCA can be implemented in a wide range of software available on the market, and the type of assessment to be done will dictate which software is used [21]. LCA has been used since 1990, and specifically, current regulations introduce the *cradle-to-grave* as the common way to state the attributional LCA. For instance, the international standard ISO 14040 declares: "LCA studies the environmental aspects and potential impact throughout a product's life (i.e., cradle-to-grave) from raw material acquisition through production, use and disposal. The general categories of environmental impacts needing consideration include resource use, human health, and ecological consequences" [22]. LCA is, hence, a systematic analysis that can be used to evaluate the alternatives for environmental improvement as a support for the decision-making process. The system boundaries of the building's LCA can be of three types: *cradle-to-grave*, *cradle-to-gate*, and *gate-to-gate*. The *cradle-to-gate* approach is an assessment of a partial life cycle of a product, from resource extraction to the factory gate, before the product is transported to the consumer. It is usually used as a basis for the environmental product declaration [23]. The *gate-to-gate* approach is a partial analysis that looks at only one process in the entire production chain. Information about each gate-to-gate module can be linked accordingly in a product chain, including information about the extraction of raw materials, transportation, disposal, and reuse, to provide a full cradle-to-gate evaluation. The *cradle-to-grave* approach is the most used because it starts from the pre-use phase, including raw material acquisition, goes through manufacturing and transportation to site, and terminates with the end-of-life phase, which includes demolition, recycling potential, landfill, and reuse [24].

In recent years, the consequential LCA has been increasingly used in the building industry and construction sector, but this study concentrates on the rating systems for assessing the environmental performance of buildings, so both attributional and consequential LCA approaches are outside its scope.

2.2. Rating Systems for Assessing the Environmental Performance of Buildings

The rating systems for assessing the environmental performance of buildings are intended to establish an objective and comprehensive method for evaluating a broad range of environmental performance. The aim of these schemes is to measure the performance of a building in a consistent and harmonized manner with respect to pre-established standards, guidelines, factors, or criteria. Scoring methods [25] have been used the most to create rating systems for assessing the environmental sustainability of buildings and are based on four major components:

- *Categories*: these form a specific set of items relating to the environmental performance considered during the assessment;
- *Scoring system*: this is a performance measurement system that cumulates the number of possible points or credits that can be earned by achieving a given level of performance in several analyzed aspects;
- *Weighting system*: this represents the relevance assigned to each specific category within the overall scoring system;
- *Output*: this aims at showing, in a direct and comprehensive manner, the results of the environmental performance obtained during the scoring phase.

This structure is used by all rating systems for assessing the environmental impact of buildings, but when the details are examined specific adaptations may diverge in several significant parts.

2.3. Rating Systems for Assessing the Environmental Impact of Buildings in the World

The Building Research Establishment Environmental Assessment Method (BREEAM) was the first scheme aimed at assessing the environmental impact of a building. It was introduced in 1990 [26,27], and, since then, the field of the rating systems for assessing the environmental impact of buildings has been subject to a rapid increase in the number of schemes developed and introduced on the market worldwide [12]. This phenomenon seems to have reached stabilization in the last few years (Figure 2).

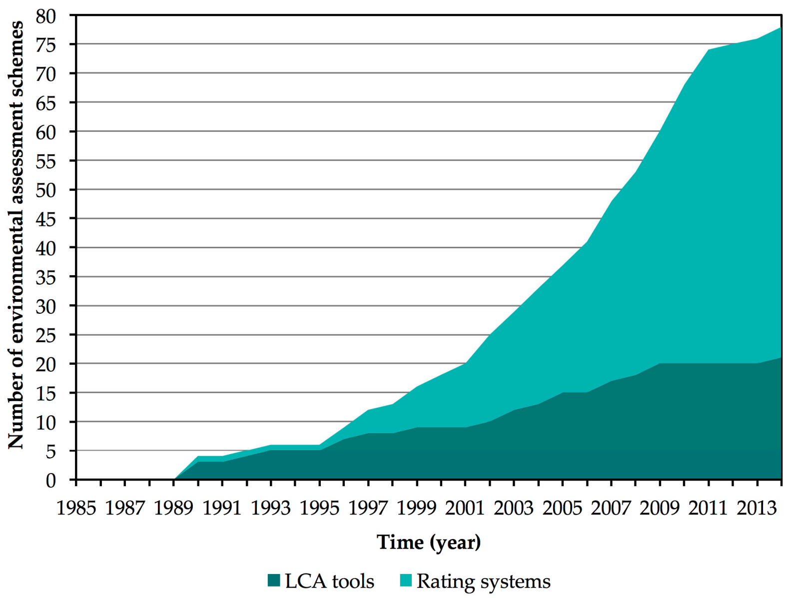

Figure 2. Trend of the schemes used for assessing the environmental impact of buildings presented worldwide from 1990 to 2014. LCA: life cycle assessment.

Table A1, shown in Appendix A, lists more than 70 sustainable building assessment systems released worldwide, including LCA schemes and the rating systems, and provides additional information. Figures 2 and 3 graphically represent the data collected in Table A1, exploiting their temporal evolution and their geographical distribution. The highest rate of introduction of new schemes was registered between 1995 and 2010. After 2010, the rate went down. The rating systems represent the larger share of all schemes presented worldwide and show a logistic growth. Conversely, the trend of the LCA schemes develops quite linearly.

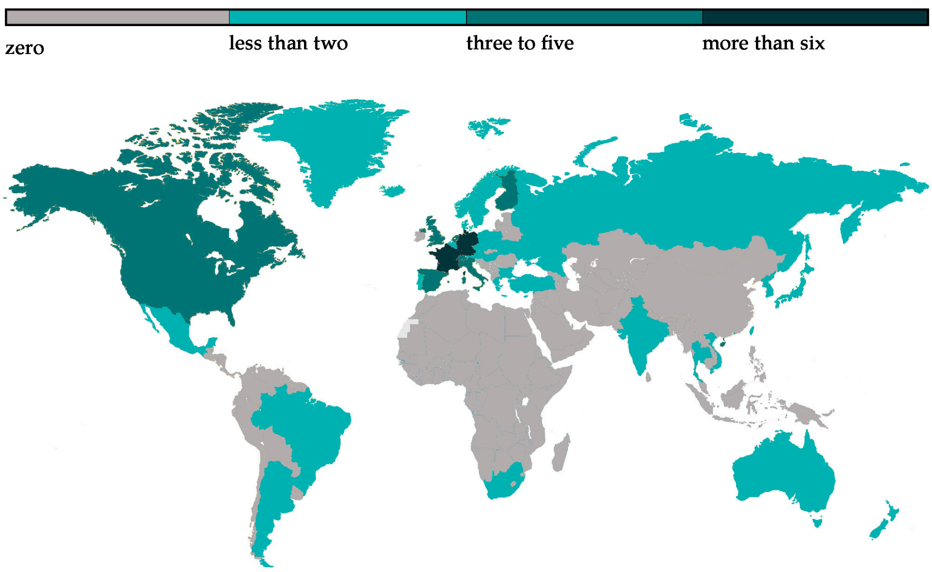

Figure 3. Number of rating systems for assessing the environmental impact of buildings available per country.

The geographical distribution of the collected tools is as follows: 54 schemes in Europe, 15 in Asia, 8 in North America, 3 in both Oceania and South America, and almost 0 in Africa and Middle Eastern countries. Furthermore, some schemes (e.g., the Sustainable Building Tool (SBTool) and SPeAR) cannot be attributed to any specific country or continent. However, the three schemes available in South America are just a customization of frameworks originally developed in other continents.

3. Methodology

As already mentioned, this paper focuses on the rating systems. The great majority of data used in this study was acquired directly from the official technical manuals for the rating schemes. Additional material was collected from the official homepages of the certification organizations or from previous scientific review papers. However, the literature concerning the schemes and their structure and content is rather limited and most of the proposed reviews only pertain to applications of the schemes to local case studies. In this paper, the selected schemes were not applied and tested on case studies and the analysis exclusively focuses on the elaboration and evaluation of the officially declared attributes of the frameworks.

For this study, only environmental rating systems for assessing the environmental performance of buildings have been considered and no benchmarking or evaluation software (e.g., ATHENA, BeCost, BEES, Eco-Quantum, Envest 2, EQUER, LEGEP®, PAPOOSE, ABCplanner, Green Globe 21, BEAT, PLACE3S, SCALDS, SPARTACUS) has been further analyzed. An analysis of a few evaluation tools can be found in [12]. Moreover, among all the rating systems available worldwide, only those that meet all the following four criteria were considered in the subsequent analyses:

1. An exclusive focus on buildings;
2. Scientific interest: cited in at least 20 papers reflected in the *Elsevier's Scopus* database; the search was executed on article titles, abstracts, and keywords.
3. Widespread adoption: more than 500 certified projects;
4. A consolidated development state: more than 5 years of service.

As shown in Table 1, only six rating systems met the four selection criteria, and will be described in Section 4:

1. Leadership in Energy and Environmental Design (LEED®), United States;
2. Building Research Establishment Environmental Assessment Methodology (BREEAM), United Kingdom;
3. Comprehensive Assessment System for Built Environment Efficiency (CASBEE), Japan;
4. SBTool, international;
5. *Haute Qualité Environnementale* (HQE™), France;
6. *Deutsche Gesellschaft für Nachhaltiges Bauen* (DGNB), Germany.

Table 1. Evaluation of rating systems against the identified four selection criteria.

Rating System	Research Keys in Elsevier's Scopus (5 April, 2017)	Citations in Scopus	Certified Projects	Years of Development
LEED	leed OR "leadership in energy and environmental design" AND sustainable AND building AND (assessment OR evaluation)	256	89,600	19
BREEAM	breeam OR ("bre environmental assessment method" OR "building research establishment environmental assessment methodology") AND sustainable AND building AND (assessment OR evaluation)	132	>559,000	26
CASBEE	casbee OR "comprehensive assessment system for built environment efficiency" AND sustainable AND building AND (assessment OR evaluation)	47	>14,000 [a]	11
SBTool	sbtool AND sustainable AND building AND (assessment OR evaluation)	28	<2000	21
HQE™	hqe OR ("haute qualité environnementale" OR "High environmental quality") AND sustainable AND building OR (assessment OR evaluation)	24	380,000 [b]	23
DGNB	dgnb OR "deutsche gesellschaft für nachhaltiges bauen" AND sustainable AND building AND (assessment OR evaluation)	24	>718	8
Green Star	"green star" AND sustainable AND building AND (assessment OR evaluation)	19	1450	9
GreenGlobes	greenglobes OR "green globes" AND sustainable AND building AND (assessment OR evaluation)	10	1200	17
Green Mark	"green mark" AND sustainable AND building AND (assessment OR evaluation)	6	3000	12
NABERS	nabers OR "national australian built environment rating system" AND sustainable AND building AND (assessment OR evaluation)	5	15,000	16
EEWH	eewh AND sustainable AND building AND (assessment OR evaluation)	5	4300	18
TERI-GRIHA	teri-griha OR "teri green rating for integrated habitat assessment" AND sustainable AND building AND (assessment OR evaluation)	0	875	10
BEAM Plus	"beam plus" AND sustainable AND building AND (assessment OR evaluation)	6	467	21
LEnSE	lense AND sustainable AND building AND (assessment OR evaluation)	4	N/A	9
PromisE	promise AND finland AND sustainable AND building AND (assessment OR evaluation)	0	N/A	11
ESCALE	escale AND sustainable AND building AND (assessment OR evaluation)	0	N/A	16
Økoprofil	økoprofil OR ecoprofil AND sustainable AND building AND (assessment OR evaluation)	0	N/A	18
SICES	sices OR "sustainability index of a community energy system" AND sustainable AND building AND (assessment OR evaluation)	0	N/A	N/A
SPeAR®	spear OR "sustainable project appraisal routine" AND sustainable AND building AND (assessment OR evaluation)	3	N/A	17
LiderA	lidera OR "liderar pelo ambiente para a construção sustentável" AND sustainable AND building AND (assessment OR evaluation)	5	24	12
CEPAS	cepas OR "comprehensive environmental performance assessment scheme" AND sustainable AND building AND (assessment OR evaluation)	1	N/A	15
SBAT	sbat OR "sustainable building assessment tool" AND sustainable AND building AND (assessment OR evaluation)	14	N/A	15
GHEM	ghem OR "Green home evaluation manual" AND sustainable AND building AND (assessment OR evaluation)	0	N/A	N/A
GOBAS	gobas OR "green olympic building label" AND sustainable AND building AND (assessment OR evaluation)	0	N/A	14
ESGB	esgb OR "evaluation standard for green building" AND sustainable AND building AND (assessment OR evaluation)	12	N/A	11
LOTUS	lotus OR "sustainable building assessment system" AND sustainable AND building AND (assessment OR evaluation)	3	12	10

[a] updated in 2015; [b] updated in 2016; N/A: not available; LEED: Leadership in Energy and Environmental Design; BREEAM: Building Research Establishment Environmental Assessment Methodology; CASBEE: Comprehensive Assessment System for Built Environment Efficiency; HQE: *Haute Qualité Environnementale*; DGNB: *Deutsche Gesellschaft für Nachhaltiges Bauen*; SBTool: Sustainable Building Tool.

Next, these six schemes are thoroughly analyzed in Section 5 to explore similarities and differences between them and to, eventually, identify implications for the design of buildings. To this purpose, the selected rating schemes are grouped into homogeneous categories, and data is compared regarding geographical coverage, design purpose, and requirements, etc. Finally, some general conclusions are drawn.

4. Description of the Selected Rating Systems

The six selected rating systems are described in this section. Exploitation of categories, scoring, weighting and outputs, the structure, and the main features of each system are presented.

4.1. Building Research Establishment Environmental Assessment Methodology (BREEAM)

Conceived in the UK in 1988 by the Building Research Establishment, the Building Research Establishment Environmental Assessment Methodology (BREEAM) was launched in 1990. Currently it has been used in around 556,600 certified buildings all around the world and more than two million buildings have been registered for assessment since its launch in 1990.

The scheme is composed of ten categories describing sustainability through 71 criteria in total. A percentage-weighting factor is assigned to each category, and the overall number of 112 available credits is proportionally assigned. However, there are some constraints on the credit assignment: indeed, a minimum achievement is required for the categories *Energy and* CO_2 and *Water and Waste*, which are reported in Table 2 where the categories for each scheme are listed.

Table 2. BREEAM: categories for each scheme.

Rating System	Categories																		
	Energy and CO_2 emissions	Water	Materials	Surface Water Run-Off	Waste	Pollution	Health and Wellbeing	Ecology	Management	Governance	Social and Economic Wellbeing	Resource and Energy	Land Use and Ecology	Transport and Movement	Innovation	Landscape and Heritage	Integrated Design	Stakeholders	Resilience
BREEAM Communities 2012										•	•	•	•	•					
BREEAM New construction 2016	•	•	•		•	•	•		•				•	•	•				
BREEAM In-use 2015	•	•	•		•	•	•		•				•	•					
BREEAM Infrastructure 2016	•	•	•		•	•	•						•	•	•	•	•	•	•
BREEAM Nondomestic refurbishment 2015	•	•	•		•	•	•		•				•	•	•				
EcoHomes	•	•	•		•	•	•		•				•	•	•				
Code for sustainable homes	•	•	•	•	•	•	•	•	•										

4.2. Comprehensive Assessment System for Built Environment Efficiency (CASBEE)

The Comprehensive Assessment System for Built Environment Efficiency, usually referred to by the acronym CASBEE, is the Japanese sustainability rating system for buildings. It was developed in 2001 by the Japan Sustainable Building Consortium (JSBC), which is a nongovernmental organization comprising the Japanese government, academic partners, and industry [28]. In 2005, it was launched on the international market and, since 2011, it has become mandatory in 24 Japanese municipalities. CASBEE is structured to have several schemes that depend on the size of a building and address the four main building life phases:

- CASBEE for Predesign, for use in site selection and building planning;
- CASBEE for New Construction, to be used in the first three years after building completion;

- CASBEE for Existing Buildings, to be used after at least one year of operation;
- CASBEE for Renovation, which is intended to support a building refurbishment.

To fulfill the specific purposes, CASBEE also features a huge batch of supplementary rating systems that are relevant when the basic version cannot be used, such as *detached houses*, *temporary constructions*, *heat island effect*, *urban development*, and *cities and market promotions*.

CASBEE assesses a building project using a metric called *building environmental efficiency* (*BEE*), which is given by the ratio between the two metrics *built environmental quality* (*Q*) and *built environmental load* (*LR*)

$$BEE = \frac{Q}{LR}$$

Q calculates the "improvement in everyday amenities for the building users, within the virtual enclosed space boundary" and *LR* quantifies the "negative aspects of environmental impact that go beyond the public environment" [29]. *Q* and *LR* range between 0 to 100 and are computed based on three subcategories, tabulated on a score sheet, as reported in Table 3.

Table 3. CASBEE's score sheet.

Scoring for Q	Scoring for LR
Q1: Indoor environment	LR1: Energy
Q2: Quality service	LR2: Resources and materials
Q3: Outdoor environment on site	LR3: Off-site environment

BEE is expressed as the gradient of a line on a graph that has LR on the *x*-axis and Q on the *y*-axis. Based on the BEE value, a level of performance (i.e., S, A, B+, B−, and C) is associated with a given project. For additional details, see the CASBEE official website [30]. The values calculated in each category are represented on a radar chart. The assessment results sheet analyses and applies weights, using coefficients for each item and the Q and LR values and produces, as a last step, an overall score conveyed through the BEE index [31]. This index is used to assess the six categories covered by the CASBEE evaluation: *indoor environment*, *quality of service*, *outdoor environment (on-site)*, *energy*, *resources and materials*, and *off-site environment*.

4.3. Deutsche Gesellschaft für Nachhaltiges Bauen

The *Deutsche Gesellschaft für Nachhaltiges Bauen*, referred to by the abbreviation DNGB, was developed by the *Deutsche Gesellschaft für Nachhaltiges Bauen* (German Sustainable Building Council), which was founded in 2007, with the collaboration of the Federal Ministry of Transport, Building and Urban Affairs. The DNGB was lunched in 2009 with the aim of promoting building sustainability in Germany and developing a German certificate for sustainable buildings [32]. The DGNB refers to the Environmental Product Declaration developed according to the standards ISO 14025 [33] and EN 15804 [34] and is mostly based on quantitative measures calculated using the life cycle assessment approach. This evaluation system is flexible and can be applied to national and international environmental assessment, including 13 different building types and, since 2011, entire urban districts. The evaluation is based on 63 criteria, subdivided into six categories that are weighted by a specific weighting factor (Table 4). The sum of the points obtained in all the categories provides the overall score for the building. Each criterion can receive a maximum of 10 points. Four categories (*ecological quality*, *economical quality*, *socio-cultural and functional quality*, and *technical quality*) have equal weight in the assessment, while *process quality* is less important (see weights in Table 4); thus, the DGNB system gives the same importance to the economic, ecological, sociological, and technical aspects of an intervention.

Table 4. DGNB: categories, weights and category descriptions.

Category	Weighting Factor	Description
Ecological quality	22.5%	Ecological impacts on local and global environment of the building's construction, utilization of renewal resources, waste, water and land use.
Economical quality	22.5%	Life cycle cost and monetary values.
Socio-cultural and functional quality	22.5%	Health, comfort, user satisfaction, cultural backgrounds, functionality and assurance of design quality.
Technical quality	22.5%	Fire and noise protection, quality of the building shell and ease of maintenance.
Process quality	10.0%	Quality of planning and design, construction process, building use and maintenance and quality of the construction activities.
Quality of the location	Rated independently	Transport-related topics, risks and image of location.

There are some specific minimum requirements that must be considered, such as the *indoor air quality* and the *Design for all* requirements included in the *socio-cultural and functional quality* criterion, and the *legal requirements for fire safety and sound insulation* included in the *technical quality* criterion. It is necessary to achieve a minimum required level in each quality section to obtain the evaluation.

4.4. Haute Qualité Environnementale (HQE™)

The *Haute Qualité Environnementale* standard, referred to by its abbreviation HQE™, was developed in 1994 in France by the HQE™ association [35]. This association supports stakeholders, designers, partners, developers, and users during a project's phases and aims to guarantee a high environmental quality of buildings. The HQE™ Association has developed many schemes, exploitable in France and abroad. It is structured to have three organizations in charge of delivering national evaluations (Certivèa, Cerqual, and Cèquami) and one for supporting the evaluation across the world (Cerway) [36]. HQE™ covers buildings throughout their life cycle, that is, throughout their design, construction, operation, and renovation. It is addressed to nonresidential and residential buildings, and detached houses. Furthermore, a specific scheme for the management system of urban planning and development projects is also available. The environmental performance requirements are organized into four topics that together include 14 categories. Topics are almost the same for all building types, but the targets are arranged differently for residential buildings and nonresidential buildings (i.e., commercial, administrative, and service buildings) (Tables 5 and 6, respectively).

Table 5. HQE™: distribution of targets for residential buildings.

Environment	Energy and Savings	Comfort	Health and Safety
Target 1: Building's relationship with its immediate environment	Target 4: Energy management	Target 8: Hygrothermal comfort	Target 12: Quality of spaces
Target 2: Quality of components	Target 5: Water management	Target 9: Acoustic comfort	Target 13: Air quality and health
Target 3: Sustainable worksite	Target 7: Maintenance management	Target 10: Visual comfort	Target 14: Water quality and health
Target 6: Waste management		Target 11: Olfactory comfort	

Table 6. HQE^{TM}: Distribution of targets for commercial, administrative and service buildings.

Environment	Energy	Comfort	Health
Target 1: Building's relationship with its immediate environment	Target 4: Energy management	Target 8: Hygrothermal comfort	Target 12: Quality of spaces
Target 2: Quality of components		Target 9: Acoustic comfort	Target 13: Air quality and health
Target 3: Sustainable worksite		Target 10: Visual comfort	Target 14: Water quality and health
Target 5: Water management		Target 11: Olfactory comfort	
Target 6: Waste management			

A building project obtains an assessment for each target expressed according to three ordinal levels: *basic*, *performing*, and *high Performing*. To be certified, a building must achieve the *high performing* level in at least three categories and the *basic* level in a maximum of seven categories. This rating system does not weight each category by a weighting factor, because they are considered to have the same importance throughout the assessment framework.

4.5. Leadership in Energy and Environmental Design (LEED)

The first Leadership in Energy and Environmental Design Pilot Project Program, referred to as LEED® Version 1.0, was launched in the USA in 1998 by the US Green Building Council (USGB), a nongovernmental organization that includes representatives from industry, academia, and government [37]. Since that time, the LEED® system has undergone some revisions, integrations, and national customizations. The LEED® Version 4.0 was released in 2016 and is currently in use. The LEED® Green Building Rating Systems are voluntary and are intended to evaluate the environmental performance of the whole building over its life cycle. Different schemes are designed for rating new and existing commercial, institutional, and residential buildings. Each scheme has the same list of performance requirements set out in five categories, but the number of credits, prerequisites, and available points change considerably according to the specific area of interest and the building type. Table 7 provides a description of the categories included in the LEED® environmental rating scheme.

Table 7. LEED®'s categories and description.

Category	Description
Sustainable sites	This section examines the environmental aspects linked to the building site. The goal is to limit the construction impact and verify meteoric water outflow.
Water efficiency	The section is linked to the water use, management and disposal in the buildings. The reduction of water consumption and meteoric water reuse are promoted.
Energy and atmosphere	In this section building energy performance improvement, the use of renewable sources and the energy building performance control are promoted.
Materials and resources	In this area the environmental subjects associated to the material selection, the reduction of virgin material use, the garbage disposal and the environmental impact due to transport are considered.
Indoor environmental quality	The themes considered in this section cover indoor environmental quality, taking into account for example healthiness, comfort, air renewal and air pollution control.
Innovation in design	The aim of this section is to identify the design aspects that improve on the sustainability operations in the building construction.
Regional priority	This area has the objective of encouraging the design groups to focus the attention on the local characteristics of the environment.

Almost all schemes present mandatory prerequisites and noncompulsory credits, which can be selected according to the objectives that is to be achieved. The summation of points for each credit generates the evaluation outcome. All the credits receive a single weight according to a precisely defined scoring system.

The scoring system has a maximum score of 100 points, plus there are up to 10 additional bonus points for complying with two special categories. Out of the possible total of 100 points, a minimum of 40 points should be obtained to pass the basic evaluation.

4.6. SBTool

In 1996, the international Green Building Challenge initiative, which was later named the Sustainable Building Challenge, set the goal of establishing energy and environmental performance standards that would be suitable in both international and national contexts. It was therefore necessary to identify assessment tools that, through different methodological bases, would be able to objectively assess the requirements of the environmental, economic, and social impacts of a building during its entire life cycle.

Developed by the work of representatives from 20 countries, this process led to the so-called SBMethod that was designed to offer, besides a common international standard, an easy customization with respect to individual national contexts. This method is continually updated by a technical committee managed by the International Initiative for a Sustainable Built Environment (iiSBE). The SBMethod covers the three aspects of sustainability (i.e., environmental, economic, and social impacts) from the building perspective and can be used to assess every design concept or existing building independently from its prevalent use and geometrical extension, according to the four phases: predesign, design, construction, and operation.

Originating from the SBMethod, the Green Building Tool (GBTool), as it was initially called, was later renamed the Sustainable Building Tool (SBTool). The SBTool is a generic framework for rating the environmental performance of a building by assigning scores and credits for a number of areas [38]. The method is structured in a way that means that each parameter is defined with a weight. It is a weighted assessment where the weighting factors are different for different building types, such as single buildings, residential buildings, commercial buildings, new-builds and existing constructions, or a mix of the two. The performance issues and the phases of the life cycle used for the assessment are listed in Table 8.

The system provides separate modules for the *site and building* assessments, carried out in the predesign phase, and the *building* assessments, done in the design, construction, or operation phases [39]. The performance framework of SBTool is organized into four levels, namely: (1) performance issues, (2) performance categories, (3) performance criteria, and (4) performance subcriteria [40]. Each performance issue contains categories that represent the domain in a more detailed and specific manner.

Table 8. The SBTool's issue area expressed per each phase of a building's life cycle. Adapted from [40].

Issue area	Predesign	Design	Construction	Operation
Site location, available services and site characteristics	•			
Site regeneration and development. Urban design and infrastructure		•		•
Energy and resource consumption		•	•	•
Environmental loadings		•	•	•
Indoor environmental quality		•		•
Service quality		•	•	•
Social, cultural and perceptual aspects		•	•	•
Cost and economic aspects		•	•	•

5. Comparative Analysis of the Selected Rating Systems

As already mentioned, the number of rating systems for assessing the environmental impact of buildings is high, and the goal of this section is to give insights into the subject by the analysis and comparison of a selection of existing schemes. Table 9 summarizes some information about the six schemes selected. How the schemes' categories, similarities, and differences can be exploited is displayed. In the following tables, the schemes are classified according to the following categories:

Table 9. Summary of the main features of the selected rating systems.

Rating System	Launch Year	Launch Country	Certification Body	International Versions and National Adaptations	Weighting System	Rating Levels
BREEAM	1990	UK	BRE	*International versions:* • Nondomestic refurbishment • In-use • New construction: buildings *National adaptations:* • United Kingdom • USA • Germany • Netherlands • Norway • Spain • Sweden • Austria	Applied to each category	• Unclassified • Pass • Good • Very good • Excellent • Outstanding
CASBEE	2004	Japan	JSBC	N/A	Complex weighting system applied at every level	• S • A • B+ • B− • C
DGNB 2014	2008	Germany	DGNB	*International version* • Core 14 *National adaptation:* • Austria • Bulgaria • China • Denmark • Germany • Switzerland • Thailand	Applied to each category	• Bronze * • Silver • Gold • Platinum
HQE™	1997	France	• Certivèa • Cerqual • Cèquami • Cerway	*International versions* • Non-residential building in operation 2015 • Infrastructures 2015 • Habitat and environment • Nonresidential building under construction 2015 • Residential building under construction 2015 • Management system for urban planning projects 2016	N/A	• Pass • Good • Very good • Excellent • Exceptional

Table 9. *Cont.*

Rating System	Launch Year	Launch Country	Certification Body	International Versions and National Adaptations	Weighting System	Rating Levels
LEED v.4	1998	USA	USGBC	*International versions:* • LEED v3.0 for new construction and major renovations • LEED for homes • LEED for core and shell • LEED for existing buildings: operations and maintenance • LEED for commercial interiors • LEED for schools • LEED for retail • LEED for healthcare • LEED for neighborhood development (in pilot stage) *National adaptations:* • Argentina • Brazil • Canada • Italy	All credits are equally weighted, but the number of credits related to each issue is different	• Certified • Silver • Gold • Platinum
SBTool 2016	2002	International	iiSBE	*National adaptations:* • Czech Republic (SBToolCZ) • Portugal (SBToolPT) • Italy (Protocollo Itaca) • Spain (Verde)	Applied to each category	• −1 • 0 • 1 • 3 • 5

* Level available only for existing buildings.

- Type of intervention (Table 10);
- Building type (Table 11);
- Phase of the building's life cycle (Table 12);
- Scopes (Table 13).

The first analysis aims at contrasting the selected six rating systems for assessing the environmental impact of buildings with respect to the type of intervention (Table 10). While BREEAM, CASBEE, DGNB, HQE™, and LEED® have dedicated subschemes or modules to cover all the four types of intervention, the SBTool does not provide assessment tools for building refurbishment and urban planning.

Table 10. Type of intervention covered by the selected schemes.

Rating System	New Buildings	Existing Buildings	Buildings under Refurbishment	Urban Planning Projects
BREEAM	•	•	•	•
CASBEE	•	•	•	•
DGNB	•	•	•	•
HQE™	•	•	•	•
LEED®	•	•	•	•
SBTool	•	•		

Rating schemes can be used to certify the environmental performances of different types of buildings, such as residential, office, commercial, industrial, and educational buildings, and all other buildings that do not fit into any of these building types are grouped in the field called Other types of buildings. It can be seen in Table 11 that BREEAM, CASBEE, DGNB, and HQE™ can be used with all building types. LEED® and SBTool do not include industrial buildings in their evaluation. Regarding the life cycle phase of a building, BREEAM, CASBEE, DGNB, and HQE™ cover all the four considered life cycle phases of a building. LEED® does not evaluate *predesign* or *design*, and the SBTool does not cover the *use/maintenance* phase.

Table 11. Building type assessed by the selected schemes.

Rating System	Residential Buildings	Office Buildings	Commercial Buildings	Industrial Buildings	Educational Buildings	Other Type of Buildings	Urban Planning
BREEAM	•	•	•	•	•	•	•
CASBEE	•	•	•	•	•	•	•
DGNB	•	•	•	•	•	•	•
HQE™	•	•	•	•	•	•	•
LEED®	•	•	•	N/A	•	•	•
SBTool	•	•	•	N/A	•	N/A	N/A

Table 12. Life cycle phase of the building assessed by the selected schemes.

Rating System	Predesign and Design	Construction	Post-Construction	Use/Maintenance
BREEAM	•	•	•	•
CASBEE	•	•	•	•
DGNB	•	•	•	•
HQE™	•	•	•	•
LEED®	N/A	•	•	•
SBTool	•	•	•	N/A

As a matter of fact, regarding the original categories, different items in two or more schemes often refer to the same field and, sometimes, similar denominations do not assess exactly the same attributes. We have therefore identified eight major scopes, in which the characteristic elements of all the categories have been grouped. According to this analysis, the categories that are the ones most assessed by the schemes are *energy performance* and *solid waste management*. Other important categories are *materials*, *water*, *waste water management*, and *ecology and environmental quality*, which are assessed by the great majority of schemes. The scopes that are assessed the least are those related to *resistance to natural disasters*, which are considered only by CASBEE, DGNB, and HQE^{TM}. Similarly, the category *olfactory comfort* is considered only by the schemes in HQE^{TM}, while, in the other systems, it is included in the more general category *air quality*. Finally, the *building information and users guide* is considered only by the schemes of the BREEAM collection and in some isolated cases by a few subschemes in LEED®, HQE^{TM}, and DGNB. In Figure 4, to support the results, the scopes distribution among the schemes is presented graphically.

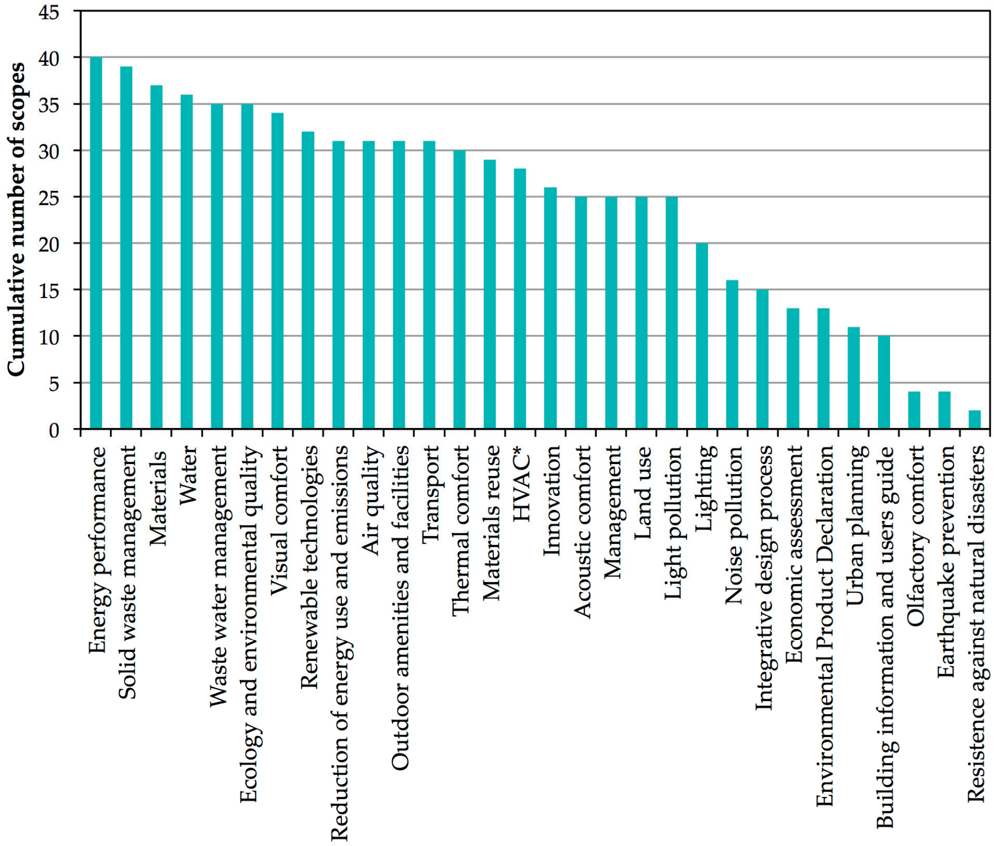

Figure 4. Scopes distribution among the analyzed rating schemes (* HVAC: heating, ventilation, and air-conditioning).

Table 13. Comparison of the scopes and criteria of the six selected rating schemes used for evaluating the sustainability of buildings.

	Scopes																													
	Energy					**Indoor Environmental Quality**					**Innovation**	**Management**				**Materials and Resources**					**Pollution and Waste**				**Resistance Against Natural Disasters**		**Site Quality**			
Rating System	**Energy Performance**	**Renewable Technologies**	**HVAC**	**Lighting**	**Reduction of Energy Use and Emissions**	**Olfactory Comfort**	**Visual Comfort**	**Thermal Comfort**	**Acoustic Comfort**	**Air quality**	**Innovation**	**Management**	**Building information and Users Guide**	**Economic assessment**	**Integrative Design Process**	**Materials Reuse**	**Environmental Product Declaration**	**Materials**	**Water**	**Land Use**	**Noise Pollution**	**Light Pollution**	**Waste Water Management**	**Solid Waste Management**	**Earthquake Prevention**	**Resistance against Natural Disasters**	**Outdoor Amenities and Facilities**	**Transport**	**Urban Planning**	**Ecology and Environmental Quality**
BREEAM																														
BREEAM Europe Commercial 2009	•	•	•	•			•	•			•	•	•	•		•		•	•	•	•		•	•			•	•		
BREEAM In-use international 2016	•	•	•	•	•		•	•	•	•			•		•			•	•				•	•			•	•		•
BREEAM New construction: infrastructure 2016 (pilot)	•										•	•		•	•	•	•	•	•		•	•	•	•				•		•
BREEAM International new construction 2016	•			•	•		•	•	•	•	•	•		•	•		•	•	•	•	•	•	•	•			•	•		•
BREEAM UK Domestic refurbishment 2014	•	•	•	•			•		•		•	•	•					•	•				•	•						•
BREEAM Nondomestic refurbishment 2015	•			•	•		•	•	•	•	•	•						•	•	•	•	•	•	•			•	•		•
BREEAM UK Datacenters 2010	•	•	•	•	•		•	•	•	•	•	•	•	•		•		•	•	•		•	•	•			•	•		•
BREEAM Communities 2012	•										•	•		•				•	•	•	•	•	•				•	•		•
Code for sustainable homes 2010	•	•		•	•		•		•			•	•						•	•	•			•						•
CASBEE																														
CASBEE for home (detached houses) 2007	•	•	•	•			•	•	•		•					•		•	•		•		•	•		•				•
CASBEE for building (new construction) 2014	•	•		•			•	•	•	•						•		•	•	•	•	•	•		•		•			
CASBEE for market promotion (offices and retail) 2014	•	•			•		•	•								•			•	•				•	•			•		•
CASBEE for urban development 2014	•				•							•		•		•		•	•	•			•	•	•		•	•	•	•
CASBEE for cities 2012														•					•	•				•			•		•	•

Table 13. *Cont.*

	Scopes																													
	Energy					Indoor Environmental Quality					Innovation	Management				Materials and Resources					Pollution and Waste				Resistance Against Natural Disasters		Site Quality			
Rating System	**Energy Performance**	**Renewable Technologies**	**HVAC**	**Lighting**	**Reduction of Energy Use and Emissions**	**Olfactory Comfort**	**Visual Comfort**	**Thermal Comfort**	**Acoustic Comfort**	**Air quality**	**Innovation**	**Management**	**Building information and Users Guide**	**Economic assessment**	**Integrative Design Process**	**Materials Reuse**	**Environmental Product Declaration**	**Materials**	**Water**	**Land Use**	**Noise Pollution**	**Light Pollution**	**Waste Water Management**	**Solid Waste Management**	**Earthquake Prevention**	**Resistance against Natural Disasters**	**Outdoor Amenities and Facilities**	**Transport**	**Urban Planning**	**Ecology and Environmental Quality**
DGNB																														
DGNB Core 14	•	•	•	•			•	•	•	•		•	•	•		•			•	•	•		•	•	•	•	•	•	•	•
HQE™																														
NF *Maison individuelle neuf* 2013	•	•	•			•	•	•	•	•		•						•	•	•	•	•		•		•		•	•	•
NF *Maison rénovée* 2014	•	•	•	•		•		•	•									•	•		•		•	•		•			•	•
NF *Logement habitat neuf*	•		•	•	•	•	•	•	•	•								•	•		•			•					•	•
NF *Qualité environementale des bâtiments* 2015	•				•	•	•	•	•	•						•			•		•			•					•	•
NF *Bâtiment durable* 2014	•					•	•	•	•	•								•	•								•	•	•	•
HQE™ Nonresidential building in operation 2015	•	•	•		•	•	•	•	•	•		•				•		•	•		•	•	•	•			•	•		•
HQE™ Infrastructures 2015				•	•				•			•		•				•	•	•	•						•	•		•
Habitat & Environnement	•			•			•	•	•	•		•	•	•		•		•	•					•				•	•	
HQE™ Non -residential building under construction 2015	•	•	•	•	•	•	•	•	•	•		•	•					•	•	•	•		•	•			•	•	•	•
HQE™ Residential building under construction 2015	•	•		•	•	•	•	•	•	•			•			•		•	•		•		•	•			•			
HQE™ Management system for urban planning projects 2016	•	•	•	•	•	•	•	•	•	•		•		•				•	•	•	•		•	•			•	•	•	•

Table 13. *Cont.*

	Scopes																													
			Energy					Indoor Environmental Quality			Innovation	Management						Materials and Resources				Pollution and Waste				Resistance Against Natural Disasters			Site Quality	
Rating System	**Energy Performance**	**Renewable Technologies**	**HVAC**	**Lighting**	**Reduction of Energy Use and Emissions**	**Olfactory Comfort**	**Visual Comfort**	**Thermal Comfort**	**Acoustic Comfort**	**Air quality**	**Innovation**	**Management**	**Building information and Users Guide**	**Economic assessment**	**Integrative Design Process**	**Materials Reuse**	**Environmental Product Declaration**	**Materials**	**Water**	**Land Use**	**Noise Pollution**	**Light Pollution**	**Waste Water Management**	**Solid Waste Management**	**Earthquake Prevention**	**Resistance against Natural Disasters**	**Outdoor Amenities and Facilities**	**Transport**	**Urban Planning**	**Ecology and Environmental Quality**
LEED®																														
LEED v4 for Homes Design and Construction																														
Multifamily mid-rise 2010	•		•		•					•		•			•			•	•	•			•	•			•			•
Homes and multifamily low-rise 2010	•	•	•	•	•					•		•			•			•	•	•			•	•			•			•
LEED v4 for Interior Design and Construction																														
Commercial interiors and hospitality	•	•	•	•	•		•		•	•	•	•			•	•	•	•	•			•		•			•		•	
Retail	•	•	•	•	•		•			•	•	•			•	•	•	•	•			•		•			•		•	
LEED v4 for Operation and Maintenance																														
Existing buildings and schools	•	•	•		•		•	•		•	•	•				•		•				•	•	•			•	•		•
Retail, data centers, hospitality, warehouses and distribution centers, multifamily	•	•	•		•		•	•		•	•	•				•		•				•	•	•				•		•

Table 13. *Cont.*

	Scopes																													
	Energy					**Indoor Environmental Quality**					**Innovation**	**Management**				**Materials and Resources**					**Pollution and Waste**				**Resistance Against Natural Disasters**		**Site Quality**			
Rating System	**Energy Performance**	**Renewable Technologies**	**HVAC**	**Lighting**	**Reduction of Energy Use and Emissions**	**Olfactory Comfort**	**Visual Comfort**	**Thermal Comfort**	**Acoustic Comfort**	**Air quality**	**Innovation**	**Management**	**Building information and Users Guide**	**Economic assessment**	**Integrative Design Process**	**Materials Reuse**	**Environmental Product Declaration**	**Materials**	**Water**	**Land Use**	**Noise Pollution**	**Light Pollution**	**Waste Water Management**	**Solid Waste Management**	**Earthquake Prevention**	**Resistance against Natural Disasters**	**Outdoor Amenities and Facilities**	**Transport**	**Urban Planning**	**Ecology and Environmental Quality**
LEED v4 for Building Design and Construction																														
Schools	•	•	•		•		•	•	•	•	•				•	•	•	•	•	•	•	•	•	•			•	•		•
Healthcare	•	•	•		•		•	•	•	•	•				•	•	•	•	•	•		•	•	•			•	•	•	•
Core and shell	•	•	•		•		•	•	•	•	•		•		•	•	•	•	•	•		•	•	•			•	•		•
New construction, retail, data centers, warehouses and distribution centers, hospitality	•	•	•		•		•	•	•	•	•				•	•	•	•	•	•		•	•	•			•	•		•
Neighborhood development	•	•									•					•			•	•		•	•	•			•	•	•	•
SBTool																														
SBTool 2012	•			•	•		•	•	•	•				•				•	•		•		•	•			•	•	•	•

6. Conclusions

In this paper, an overview of the available rating systems for assessing the environmental impact of buildings is presented. The rating systems for assessing the environmental impact of buildings are technical instruments that have been developed with the specific purpose of evaluating the environmental performances of buildings. In the last decade, a growing interest in sustainability and sustainable development has been registered due to the urgent requirement for a worldwide reduction in greenhouse gas emissions for the safety of our planet and the health of global society. This has had a remarkable impact on the building and construction industry and, consequently, a wide array of rating schemes has been developed with different purposes and features to enhance buildings' sustainability.

The core of this work is a comparative analysis of six widespread and consolidated schemes that are the most cited in the scientific literature. The present study is motivated by the need to identify differences in the rating schemes to better understand their main features and identify their possible implications. After carrying out a survey of more than 70 schemes for assessing the environmental impact of buildings, the following six schemes were selected and analyzed in depth: the Building Research Establishment Environmental Assessment Methodology (BREEAM), the Comprehensive Assessment System for Built Environment Efficiency (CASBEE), the *Deutsche Gesellschaft für Nachhaltiges Bauen* (DGNB), the *Haute Qualité Environnementale* (HQE™), the Leadership in Energy and Environmental Design (LEED®), and the SBTool.

Data was collected from technical manuals and official websites and, sometimes, through direct relationships with agents on the technical or administrative board of the companies creating these systems. In this regard, we should point out that some challenges were faced during the data acquisition process. User manuals are not always available, and information, even though it is usually publicly disclosed, often appears to be fragmentary or is only available in local languages.

We also noticed that a systematic comparison of the schemes is difficult, sometimes even prohibitive. As a matter of fact, different rating schemes have been developed for different purposes and hence a precise comparison of categories and subcategories is often not achievable.

The analysis has been carried out considering several aspects, and we discovered the following:

- All rating systems for assessing the environmental impact of buildings are suitable for both new and existing buildings and, apart from the SBTool, cover the refurbishment of buildings as well;
- BREEAM, CASBEE, DGNB, and HQE™ can be used to assess all types of buildings, while LEED® does not cover industrial buildings and the SBTool is the most limited since it does not cover urban planning projects, and building types other than residential, office, commercial, and educational buildings;
- BREEAM, CASBEE, DGNB, and HQE™ cover all the life cycle phases of a building;
- SBTool is the only system that has also been designed for certifying a low performance level of a building;
- Regarding the categories assessed by the schemes, *energy performance*, *solid waste management*, *material*, and *water* are the most considered categories from a quantitative perspective;
- The categories that are considered less are *resistance against natural disasters*, *earthquake prevention*, and *olfactory comfort*.

In conclusion, it should be noted that these schemes have been largely accepted and widely used in the building sector. Regarding future development of these schemes, desirable features are:

- Completeness, that is, analyzing in an appropriate way all the elements characterizing a building and its life cycle;
- Representing in a clear way the weighting system and supporting the scoring system with sound evidence.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Rating systems assessing the environmental impact of buildings in use worldwide. Adapted from [41].

Region	Country	Name	Owner/Management	Year	Type of Method	References
Africa	South Africa	Green Star SA	South Africa GBC	2008	Rating system	[41,42]
		SBAT	CSIR	2002	Rating system	[43,44]
Asia	China	GHEM	China Real Estate Chamber of Commerce	N/A	Rating system	[41]
		GOBAS	Minister of Science & Technology	2003	Rating system	[41,45]
		DGNB	DGNB China	2009	Rating system	[32,41,46]
		ESGB	Ministry of Housing and Urban-Rural Construction	2006	Rating system	[41,47]
	Hong Kong	BEAM Plus	HK-BEAM Society	1996	Rating system	[41,48]
		CEPAS	HK Building Department	2002	Rating system	[41]
	India	TERI-GRIHA	The Energy & Research Institute (TERI)	2007	Rating system	[41,49]
		LEED® India	Indian GBC	2011	Rating system	[41,49,50]
	Japan	CASBEE	Japan Sustainable Building Consort.	2004	Rating system	[51,52]
		NIRE-LCA	National Institute for Resource and Environment	1996	LCA tool	[53]
	Korea	GBCC	Korean Korea Institute of Energy Research	1997	Rating system	[54]
	Singapore	Green Mark	Singapore Building & Construction Authority	2005	Rating system	[55]
	Taiwan	EEWH	Architecture and Building Research Institute	1999	Rating system	[56]
	Thailand	DGNB	ARGE—Archimedes Facility—Management GmbH, Bad Oeynhausen & RE/ECC	2010	Rating system	[46]
	Vietnam	LOTUS	Vietnam GBC	2007	Rating system	[57]
Europe	Austria	BREEAM AT	DIFNI	N/A	Rating system	[58]
		DGNB	ÖGNI	2009	Rating system	[46]
	Belgium	LEnSE	Belgian Building Research Institute	2008	Rating system	[41]
	Bulgaria	DGNB	Bulgarian GBC	2009	Rating system	[46]
	Czech Republic	DGNB	DIFNI	2011	Rating system	[46]
		SBToolCZ	iiSBE International, CIDEAS	2010	Rating system	[59]
	Denmark	BEAT 2002	SBI	2002	Rating system	[12,60]
		DGNB	Denmark GBC	2011	Rating system	[32,46]
	Finland	PromisE	VTT	2006	Rating system	[41]
		BeCost	VTT	N/A	LCA tool	[12]
		KCL-ECO	VTT	1992	LCA tool	
	France	HQE™ Method	HQE™	1997	Rating system	[41]
		ELODIE	CSTB's Environment division	2006	LCA tool	[41]
		TEAM™	Ecobilan	1995	LCA tool	[12,61]
		EQUER	*Ècole des Mines de Paris, Centre d'Énergétique et Procédés*	1995	LCA tool	[12,61]
		ESCALE	CSTB and the University of Savoie	2001	Rating system	[12,62]
		PAPOOSE	TRIBU Architects	N/A	LCA tool	[12,61]
	Germany	DGNB	German Sustainable Building Council	2008	Rating system	[46]
		BREEAM DE	DIFNI	2011	Rating system	[58]
		GABI	IKP University of Stuttgart, PE Product Engineering GmbH	1990	LCA tool	
		GEMIS	Oeko-Institut (Institute for applied Ecology)	1990	LCA tool	
		LEGEP®	LEGEP Software GmbH	2001	LCA tool	[12]
		OpenLCA	GreenDeltaTC GmbH	2013	LCA tool	

Table A1. *Cont.*

Region	Country	Name	Owner/Management	Year	Type of Method	References
Europe		Umberto	Ifu Hamburg GmbH	-	LCA tool	
	Greece	DGNB	DIFNI	2010	Rating system	[46]
	Hungary	DGNB	DIFNI	2010	Rating system	[46]
	Italy	LEED® Italia	Italy GBC	2006	Rating system	[63]
		Protocollo ITACA	iiSBE Italia	2004	Rating system	[41]
		eVerdEE	ENEA	2004	LCA tool	
	Luxembourg	BREEAM LU	DIFNI	2009	Rating system	[58]
	Netherlands	BREEAM-NL	Dutch GBC	2011	Rating system	[41,58,64]
		SIMAPRO	Pre Consultants	1990	LCA tool	[65]
		Eco-Quantum	IVAM	2002	LCA tool	[12]
	Norway	BREEAM-NOR	Norwegian GBC	2012	Rating system	[12,58]
		Økoprofil	SINTEF	1999	Rating system	[66]
	Poland	DGNB	DGNB International	2013	Rating system	[46]
	Portugal	LiderA	*Instituto Superior Técnico, Lisbon*	2005	Rating system	[41]
		SBToolPT	iiSBE Portugal, LFTC-UM, ECOCHOICE	2007	Rating system	[67]
	Russia	DGNB	DGNB International	2010	Rating system	[46]
	Spain	VERDE	Spanish GBC	2006	Rating system	[41]
		DGNB	N/A	2011	Rating system	[46]
		BREEAM ES	*Fundacion Instituto Technològico de Galicia*	2010	Rating system	[58,68]
	Sweden	EcoEffect	Royal Institute of Technology	2006	Rating system	[69]
		BREEAM SE	Swedish GBC	2008	Rating system	[58]
	Switzerland	BREEAM CH	DIFNI	N/A	Rating system	[58]
		DGNB	SGNI	2010	Rating system	[46]
		Eco-Bat	University of Applied Science of Western Switzerland	2008	LCA tool	[70]
		REGIS	Sinum AG	1993	LCA tool	
	Turkey	DGNB	-	2010	Rating system	[46]
	Ukraine	DGNB	DGNB International	N/A	Rating system	[46,71]
	United Kingdom	BREEAM	BRE	1990	Rating system	[12,58,72]
		CCaLC Tool	The University of Manchester	2007	LCA tool	
		Envest 2	BRE	2003	LCA tool	[12,73]
North America	Canada	LEED® Canada	Canada GBC	2009	Rating system	[41,74]
		GreenGlobes	ECD Canada	2000	Rating system	[41,75]
		Environmental Impact Estimator	ATHENA Sustainable Material	2008	LCA tool	
		ATHENA™	ATHENA Sustainable Material Institute	2002	LCA tool	[12,73,76]
	Mexico	SICES	Mexico GBC	N/A	Rating system	[41]
	United States	LEED®	United States GBC	1998	Rating system	[12,41]
		BEES 4.0	NIST	1998	LCA tool	[12,73,77]
		GreenGlobes	Green Building Initiative	2004	Rating system	[41,75]
Oceania	Australia	Green Star	Australian GBC	2003	Rating system	[78,79]
		NABERS	NSW Office of Environment and Heritage	2001	Rating system	[80,81]
	New Zealand	Green Star NZ	New Zealand GBC	2007	Rating system	[82,83]
South America	Argentina	LEED® Argentina	Argentina GBC	N/A	Rating system	[68,84]
	Brazil	LEED® Brazil	Brazil GBC	2007	Rating system	[39,85]
		HQE™	*Fundação* Vanzolini	2014	Rating system	[35]
Generic		SBTool	iiSBE	2002	Rating system	[38,67]
		SPeAR	Ove Arup Ltd.	2000	Rating system	[86]

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