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An analysis of environmental assessment schemes and identification of their impact on building design

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To Andrea,

Abstract

The aim of this thesis is to present an overview of the available environmental assessment schemes in the building field, with the final scope of making an analytic comparison of the schemes.

The environmental assessment schemes are technical instruments having the target of evaluating the energy and environmental performances of buildings. Such schemes are specifically designed to assist the project management by providing frameworks with precise criteria assessing the environmental impact of the buildings.

The worldwide growing interest in sustainability and sustainable development had a remarkable impact on the building and construction industry. As a consequence, a large variety of assessment schemes have been established, each one with its peculiarities and fields of applicability. The present work is motivated by the interest in emphasizing such differences to better understand the assessment schemes. It also attempts to summarize in a user-friendly form the vast and fragmented assortment of information available. A deep comprehension of the state-of-the-art may lead to a more conscientious use of the schemes and allow to better identify the path for improvements and future research.

The total number of existing environmental assessment schemes is 78, these being not uniformly distributed around the globe. As a matter of fact, there are nations that have developed several schemes, such as France or US, while other nations currently have none, such as most African and Middle-Eastern countries. On the other hand, it must be noticed that some countries use only local adaptation of schemes originally developed elsewhere.

There are two main frameworks for the design of environmental assessment schemes, namely Life Cycle Assessment method and Multi-criteria Decision Making method.

The former is a quantitative method and allows to compile a rigorous evaluation of each environmental effect produced by the assessed building during its entire life cycle according to the scheme "cradle-to-grave". The latter is instead a qualitative method and is characterized by a collection of environmental, economic and social information and data, which are evaluated by means of a rating system and then summarized to give an overall sustainability score of the assessed building. The analysis performed in the thesis is focused on the six main

schemes based on Multi-criteria Decision Making method. These are: Building Research Establishment Environmental Assessment Methodology (BREEAM), Comprehensive Assessment System for Built Environment Efficiency (CASBEE), *Deutsche Gesellschaft für Nachhaltiges Bauen* (DGNB), *Haute Qualité Environnementale* (HQE™), Leadership in Energy and Environmental Design, and SB Method.

The analysis has been carried out by means of a series of tables illustrating different aspects concurring in the characterization of the schemes, such as *project type, building type, categories* and *rating systems*. The data used in the comparison have been collected from user manuals, official websites and research articles.

The final part of the thesis is devoted to analyze, on the basis of the same criteria mentioned above, two local schemes, BREEAM-Nor and *Protocollo ITACA*.

Acknowledgement

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List of Acronyms

AFOLU	Agriculture, Forestry and Other Land Use
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Method
CASBEE	Comprehensive Assessment System for Building Environmental Efficiency
CEN	European Committee for Standardization
CEPAS	Comprehensive Environmental Performance Assessment Scheme
CO_2	Carbon Dioxide
CSIR	Council for Scientific and Industrial Research
CSTB	Centre Scientifique et Technique du Bâtiment
DIFNI	Deutschen Privaten Institut für Nachhaltige Immobilienwirtschaft
EEWH	Ecology, Energy, Waste & Healthy
EIT	Economies in Transition
EMS	Environmental Management System
EPD	Environmental Product Declaration
EPI	Energy performance index
ESGB	Evaluation Standards of Green Building
F-gas	Fluorinated gas
GBC	Green Building Council
GBCC	Gree Building Evaluation Criteria
GHEM	Green Housing Evaluation Manual
GHG	Greenhouse Gases
GOBAS	Green Olympic Building Assessment Scheme
GRIHA	Green Rating for Integrated Habitat Assessment
Gt	Giga tons
$GtCO_2eq$	Giga tons of carbon dioxide equivalent
HQE™	Haute Qualité Environnementale
iiSBE	International Initiative for a Sustainable Built Environment
IPCC	Intergovernmental Panel of Climate Chang
ISO	International Organization for Standardization
ITACA	Istituto per l'Innovazione e Trasparenza degli Appalti e la Compatibilità Ambientale
IVAM	Sustainability Research and Consultancy Department of the University of Amsterdam
LAM	Latin American and Caribbean states
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LEED®	Leadership in Energy and Environmental Design
LEnSE	Label for Environmental, Social & Economic building
LiderA	Leadership for the Environment in Sustainable Building
NABERS	National Australian Building Environmental Rating Scheme
NIST	U.S. National Institute of Standards and Technology
OECD	Organization for Economic Cooperation and Development
ÖGNI	Österreichische Gesellshaft für nachhaltige Immobilienwirtschaft
PCR	Product Category Rules
SBAT	Sustainable Building Assessment Tool

SBI	Danish Building Research Institute
SETAC	Society of Environmental Toxicology and Chemistry
SGNI	Schweizer Gesellshaft für nachhaltige Immobilienwirtschaft
SINTEF	Stiftelsen for Industriell og Teknisk Forskning
SPeAR	Sustainable Project Assessment Routine
TBL	Triple Bottom Line
UNCED	United Nations Conference on Environment and Development
UNFCCC	United Nations Framework Convention on Climate Change
VTT	Technical Research Centre of Finland

Introduction

Scope and contribution

A wide variety of environmental assessment schemes is currently available on the market, each one with its particular features and its specific geographical area of authority. Such tools have been developed by different research institutions according to their own needs. However the only attempts to give an overall survey of the methods are currently out of date, as they date back to the 1990s, or rather fragmentary, i.e. providing only general information and not addressing any comparison or detailed analysis. In this regard, the scope of this thesis is making an effort to fill the gap by collecting the widest range of available information from technical manuals, official websites and direct relationships with agents in the assessment tools board. The main contributions are, from one side, the classification of all the tools and the analysis of their chronological evolution worldwide and, on the other side, the identification and the characterization of the main rules behind the evaluation criteria and scoring mechanisms.

Thesis organization

The thesis is divided into four chapters. The first one is devoted to the presentation of the background, this being fundamental to well understand the framework that has given rise to the assessment schemes and introducing useful tools for increasing understanding of the following chapters. Such background comprehends the concept of sustainability, its development and its application in the building sector, as well as the current regulations and the definition of reference standards.

The State-of-the-Art is surveyed in Chapter 2. The two main assessment approaches are identified, namely Life Cycle Assessment and Multi-Criteria Decision Making Method. A collection of all the available schemes is then proposed, providing several information such as year of introduction, promoting countries and owners/administrators. Within the group of Multi-Criteria Decision Making Methods, the six most diffused tools have been selected and thoroughly examined in Chapter 3: these are Building Research Establishment Environmental Assessment Methodology (BREEAM, United Kingdom), Comprehensive Assessment System for Built Environment Efficiency (CASBEE, Japan), *Deutsche Gesellschaft für Nachhaltiges Bauen* (DGNB, Germany), *Haute Qualité Environnementale* (HQE™, France), Leadership in Energy and Environmental Design (LEED®, United States) and SBTool (International). A short presentation of local and customized schemes concludes the chapter.

Chapter 4 is dedicated to analysis and comparison of schemes, on the basis of several parameters such as project type, building type, life cycle phase of the building and considered evaluating criteria with the associated weighting systems.

Finally, two national schemes, namely *Protocollo ITACA* (Italy) and BREEAM - Nor (Norway), have been examined and compared in Chapter 5. The motivation behind this choice is that the present thesis is the result of a joint work between University of Rome Tor Vergata, Italy and Norwegian University of Science and Technology, Norway.

A resume of the contribution of the thesis is proposed in the Conclusion section.

Chapter 1

From sustainability to the environmental assessment schemes

This background chapter provides the preliminary knowledge for understanding the sustainability concept and its evolution. The attention is focused on the main historical steps, starting with Stockholm conference in the 1972 and ending with the recent Lima summit in 2014. The concepts of *Social sustainability*, *Economic sustainability,* and *Environmental sustainability* are defined to explain the process of *Sustainable development*. Some data are given about the *Greenhouse gases* (GHGs), specifying the implication of the building sector in the climate change. An overview of current regulations is issued and, moreover, the meaning of the *benchmarks* is explained summarily.

1.1 The concept of sustainability and its development

The concepts of sustainability and development are strictly related to each other. In order to understand the evolution of the first one is necessary to explain how the wrong interpretation of the second one has led to an overuse of the environmental resources. The increasing human knowledge and the technological development, conceived as human triumph over nature [1], brought quickly to a rapid exploitation of the natural resources without ensuring a maximum long-term use. The beginning of interest on the environmental sustainability is recognizable in the second half of the twentieth century when, the emerging awareness of the planet damages has driven the world community to struggle with the problem of the climate changes.

One of the most important steps about the sustainable development and this topic took place in the 1972 with the "United Nations Conference on the Human Environment" in Stockholm. The subjects argued led to the adoption of a declaration, based on 26 principles about the rights and the human being's responsibility on the environment, including: (i) everyone's right to appropriate living conditions, (ii) the important role of the nature within the legislative and economic process of the States, and (iii) the preservation of the natural resources, conveniently protected in respect of the future generations.

This attention to the needs of "future generation" is comparable with the one that, later in 1987, has been given by the World Commission on the Environment and Development, often just referred as Brundtland Commission. The final report delivered by the Brundtland Commission, entitled "Our common future" is also known as Brundtland's report. It is a milestone in the field and defines the sustainable development as the *"ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs*" [2]. Even though the Brundtland Commission's definition of sustainability may appear well fitting, it could be deceptive about the complexity of the subject and about the contradictions surrounding what the sustainability is. Although these concepts in that period were still at an early stage, they can be considered as a starting point of the evolution and spread of the sustainability concept. They gave a great contribution in opening the way to a process culminated in 1992 with the first Earth Summit in Rio de Janeiro [3-6]. This United Nations Conference on Environment and Development (UNCED), in which the delegations of 183 countries were involved, ended with the agreement best known as the United Nations Framework Convention on Climate Change (UNFCCC).

The ultimate objective of the Convention was to establish the reduction of the greenhouse gases in the atmosphere and bring the carbon dioxide (CO_2) emission below a mandatory level that would not have damaged permanently the planet. It states that "*such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner*" [7].

The UNFCCC was implemented in Kyoto on 11th December 1997 where the Member States committed an international treaty called "*The Kyoto Protocol*". The first commitment period started in 2008 and ended in 2012. The *Kyoto protocol* is based on the principle that each country has to diversify the responsibilities in the environmental filed, in order to stabilize the atmospheric concentration of GHG at a level that "would stop dangerous anthropogenic interference with the climate system" [8]. It only binds developed countries because it recognizes that they are largely responsible for the current high levels of GHG emissions in the atmosphere resulting from more than 150 years of industrial activity. The general targets proposed for these countries were to reduce their GHGs emissions by about

5 % below their 1990 levels. In Doha, Qatar, on December 2012, the *Doha Amendment* was adopted. This launched a second commitment period, starting on 1 January 2013.

Over these years many annual conferences on the climate changes took place around the world and the last one was held in Lima, Peru in 2014. The 183 Parties of the Kyoto Protocol have elaborated the elements of the new agreement, scheduled to be approved in Paris in late 2015. One of the goals is to establish a path that gradually leads to limit the global average Earth temperature increase below 2 °C above the pre-industrial levels [9]. All Members States have to ensure significant global GHG emission reductions over the next few decades, reading as a 40 ÷ 70 % reduction in emissions below 2010 levels by 2050 and near-zero emissions of CO_2 by the end of the century[7].

The concept of sustainable development has not a single accepted definition. It includes the integration of economic growth with the other important elements that made the development healthy, such as the eradication of poverty, environmental protection, job creation, security and justice.

To investigate the notion of sustainability it is necessary to analyze all the aspects related to this field, which are related to this field, which are grouped into three components to emphasize social, environmental and economics environmental and economics dimensions. This division (

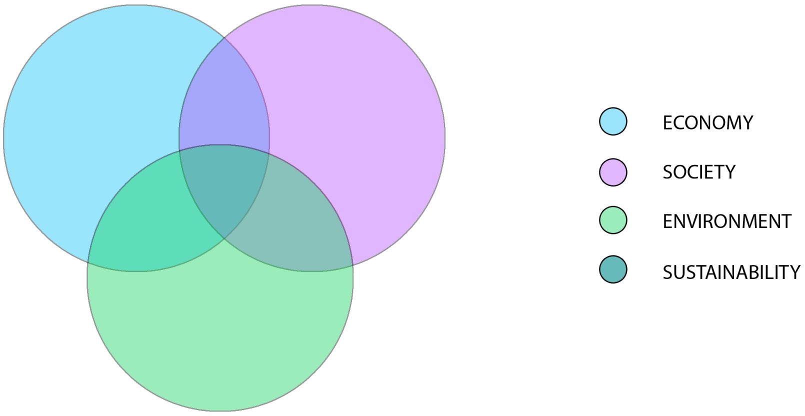

Figure 1), called the Triple Bottom Line (TBL) of sustainability, has been introduced by Elkington in 1994 and it is used to evaluate each aspect of sustainability [10].

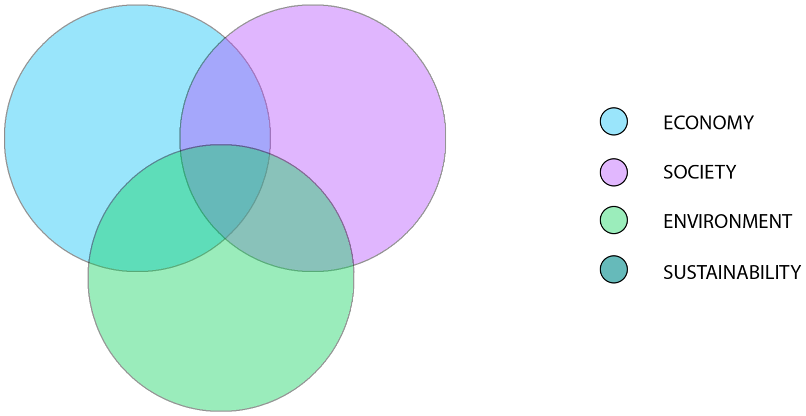

Figure 1 Triple bottom line of sustainability.

The TBL is a framework that measures the impact of an organization's activities, evaluating its social, human and environmental capital [11]. The aim of this framework is to consider the impact of resources consumption and the value creation in terms of integration among these three requisites, equalizing the importance of each one.

According to the Western Australia Council of Social Services, the *Social Sustainability* regards 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 [12]. Human capital is nowadays accepted as a part of economic development [13].

On this regard it is necessary to define the *Economic Sustainability* as the optimal employment of existing resources, so that a responsible and beneficial balance can be achieved over the long-term in order to reach the preservation of the capital. It concerns the real economic impact that the society has on its economic environment.

The last definition to be given in order to complete the triad of the TBL is the *Environmental Sustainability.* It can be defined as the capacity to use the natural resources without exceed their regenerative capacity, protecting the "natural capital" in order to prevent harm to humans and environment. This means constraining the scale of the human economic system within the biophysical limits of the overall ecosystem on which it depends: environmental sustainability needs sustainable production and sustainable consumption [12].

1.2 Sustainability in the building field

The industrial sectors, including the building sector, started to recognize the impact of its activities on the environment in the 1990s [14]. In the last two decades, the interest on the climate change has had a huge grown. The concentration of GHGs in the atmosphere, including CO_2 and methane (CH_4), has been steadily rising since the beginning of the Industrial revolution [15, 16].

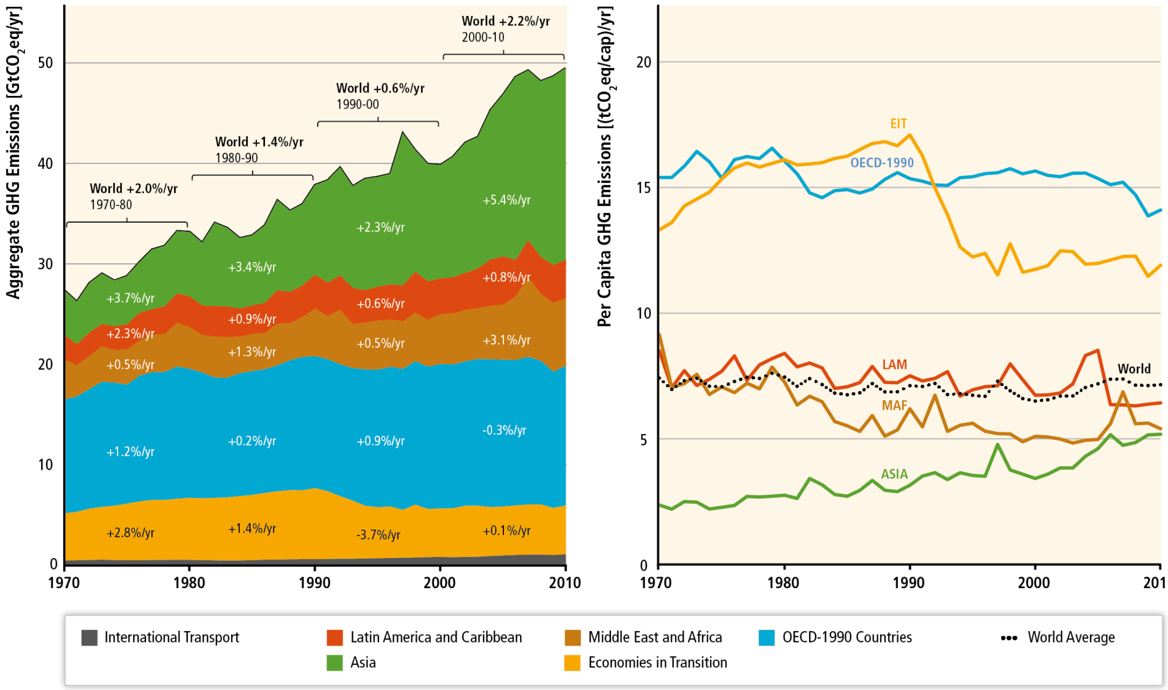

Figure 2 Left panel: GHG emissions per region over 1970-2010. Emissions include all sector and gases using 100-year GWP values. Right panel: The same data presented as per capita GHG emissions. The graphs are referred to Latin America and Caribbean (LAM), Asia, Middle East and Africa (MAF), Economies in Transition (EIT) and member countries of the Organization for Economic Co-Operation and Development (OECD-1990). Source: [17, 18].

In Figure 2 the global GHG emissions have a stationary trend over the last 40 years. The most increasing regional trend over the last two decades is noticeable in Asia, while in regions other than EIT [19] the trend has been fairly flat until the last few years when emissions have decreased in LAM and in the group of member countries of the OECD-1990.

The scientific research about this topic made efforts to design and adopt policies at local, national and international level to mitigate the emissions of pollutants. The aim of these strategies is promoting the human welfare and job, but also increase the public knowledge about the new technologies for decreasing the emissions amount. The attention on this field was pointed out by the international diplomacy, such as the UNFCCC and the Kyoto Protocol, which played an important role focusing the attention on mitigation of GHGs.

Figure 3 shows the change of the quantity of emission from 1990 to 2010 for the countries involved in the Kyoto Protocol. The data are presented in a histogram that divides the countries in three groups: in red, the Annex B countries that have formally ratified the protocol and have bound targets; in yellow, the non-members countries, which are signatories to the Protocol but have not ratified or withdrew (Canada); in blue, the non-Annex B countries, which joined the Protocol but have no quantitative emission control targets.

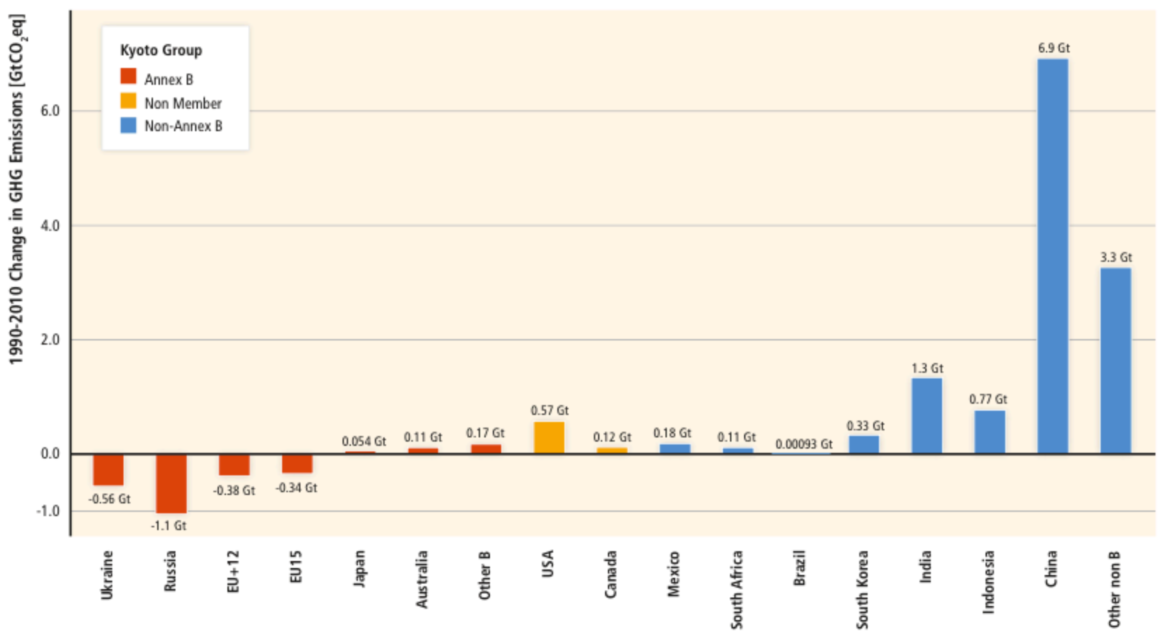

Figure 3 Change in GHG emissions in the countries involved in the Kyoto protocol. Source: [7].

Figure 3 shows that, since 1990 the Annex B countries, excluding United States and Canada, have reduced their emissions by 20 % and the countries with the major decline are Ukraine, Russia and the 12 EU Member States It is clear that the country with the largest increase of GHGs emission is China, with a rate of 6.9 $GtCO_2eq$ from 1990 to 2010. The mitigation process, in which the countries are involved, is nowadays the main effort addressed for the control of the employment of natural resources and its impact on the environment. It involves notably the emissions of GHGs and other pollutants coming from the different human activities and modifying the planet energy balance.

Figure 4 shows the total amount of direct and indirect GHG emissions for each sector: (i) industry 31.5 %, (ii) agriculture, forestry and other land use (AFOLU) 23.87 %, (iii) buildings 18.57 %, (iv) transport 14.4 %, and (v) energy 33.6 %. The pull-out in Figure 4 emphasizes the indirect CO_2 emissions coming from electricity and heat production used in the other sectors.

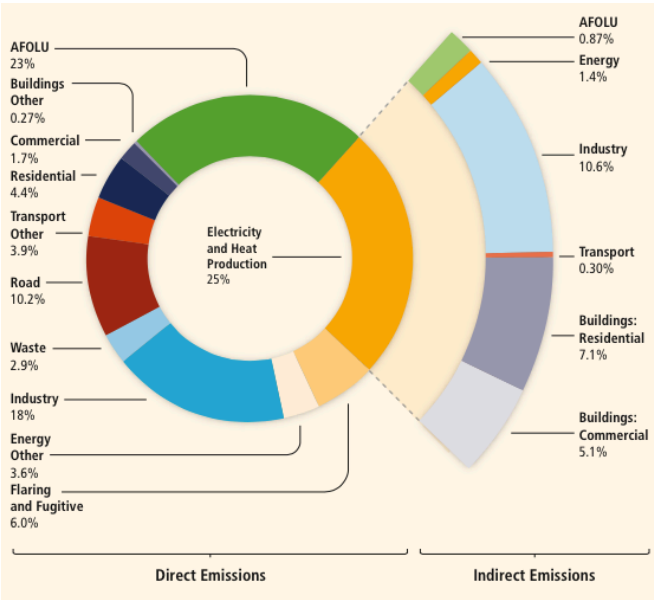

Figure 4 Allocation of total GHG emission in 2010 per sector. Source: [7].

Focusing on the building sector, the 2014 Intergovernmental Panel on Climate Change's (IPCC) report points out some significant data about its involvement in the climate change and related emissions. In 2010 the building sector accounts 32% of total global final energy use (24% for residential and 8% for commercial), 19% of energy-related GHG emissions (including electricity-related emissions), 51% of global electricity consumption and a significant amount of fluorinated greenhouse gases (F-gas) emissions [20].

Figure 5 shows the amount of direct and indirect emissions coming from the building sector from 1970 to 2010. It can be observed that most of the GHG emissions, approximately

6 $GtCO_2eq$, come indirectly from electricity use in buildings, while the direct emissions in the same period are rather stationary.

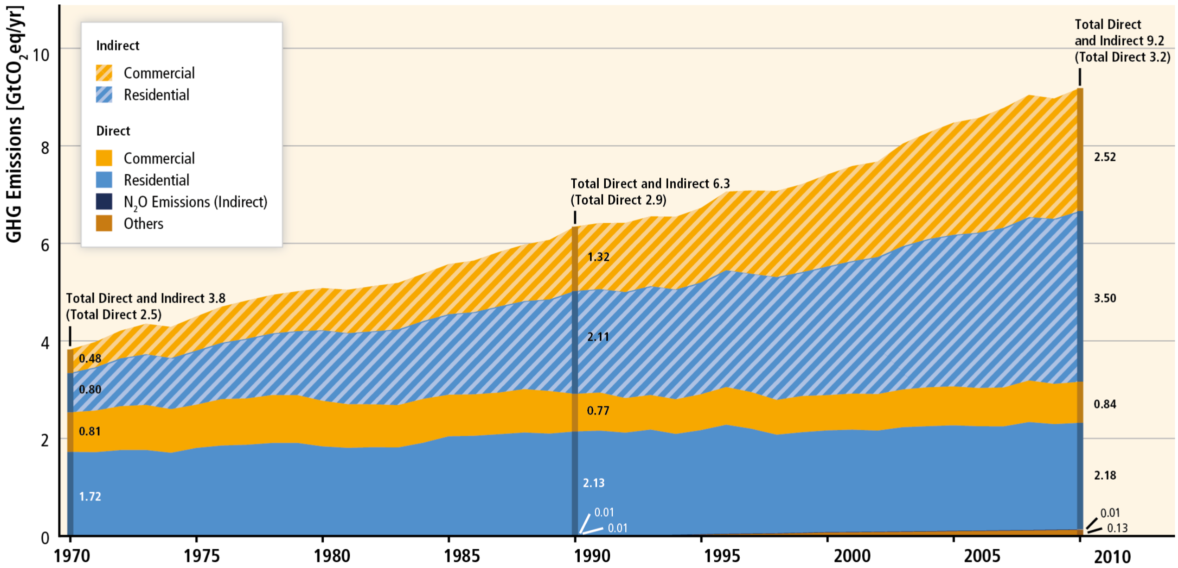

Figure 5 Direct and indirect emissions in the building sector from 1970 to 2010. Source: [20].

To clarify the meaning of these data is necessary to characterize the difference between direct and indirect emission. The Greenhouse Gas Protocol classifies the emissions into three broad scopes, based on the source of emissions:

- Scope 1: direct GHG emissions coming from sources that are owned or controlled by an entity;
- Scope 2: indirect GHG emissions are consequence of the activity of an entity that exploits at sources owned or controlled by another entity (i.e. consumption of purchased electricity, heat or steam);
- Scope 3: other indirect emissions such as transport-related and electricity-related not covered in Scope 2.

It has been demonstrated that the building sector has significant mitigation potentials due to the large cost-effective opportunities as well as the broad variety of co-benefits [21]. A significant share of these emissions can be avoided cost effectively through improved energy efficiency, while providing the same or higher level of energy services. The reasons for this include the widespread and fragmented nature of the efficiency potential among buildings and among end-users [22]. A wide range of practices and cases demonstrate energy savings in building as high as 80 % at little or no extra cost [23, 24] with an edge of reduction between 50 % and 90 % in new buildings and 50 % and 75 % in existing buildings [20].

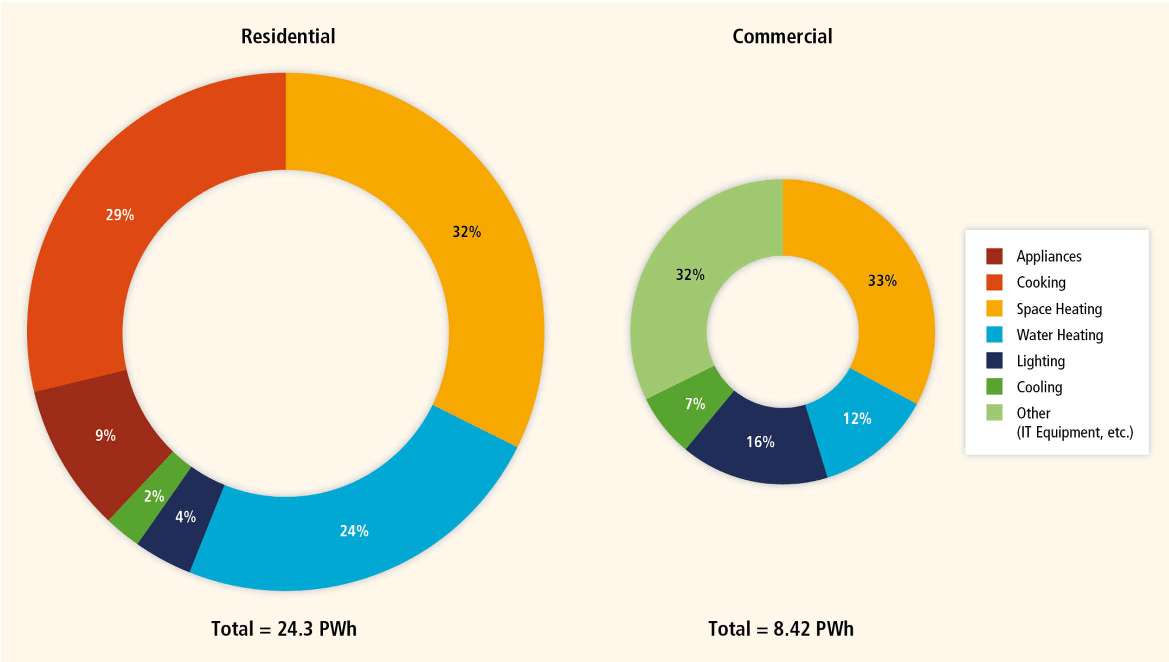

Figure 6 World building delivered energy consumption by end-use in 2010. Source: [25].

Figure 6 shows the world final energy consumption by end-use in 2010. It is clear that space heating represents the higher percentage of the delivered energy consumption for both residential and commercial use.

According to [20], the development of the technology may potentially reduce by half or more the specific energy use. The more relevant efforts and improvements are expected in day and electric lighting, household appliances, insulation materials, heat pumps, indirect evaporative cooling to replace chillers in dry climates, fuel cells, digital building automation and control systems, smart meters and grids as a mean of reducing peak demand and accommodating intermittent renewable electricity sources.

1.3 Current regulations

The increasing interest raised by the climate change and by the environmental sustainability has led to the necessity of creating a set of rules useful to establish common standards. The aim of these regulations is to promote a worldwide uniformity of guidelines to enhance sustainability in the environmental framework. This also contributes to facilitate the international trade.

Two main contributions to reach this goal were given by the *International Organization for Standardization* (ISO) and, in Europe, by the *European Committee for Standardization* (CEN). These two bodies work to regulate the environmental field and also to safeguard consumers and end-users of products and services. They ensure that certified products are conforming to the minimum standards set internationally.

Focusing on the building sector, the ISO instituted a technical committee named ISO/TC 59 "*Building and civil engineering works*". It has the scope to standardize the terminology and the performance requirements in the building and civil engineering processes. The technical committee has a number of a subcommittees related to some specific aspects, namely: 17/WG TC/SC 1 – *General principles and terminology*; 17/WG TC 59/SC 2 – *Indicators of sustainability*; 17/WG TC 59/SC 3 – *Environmental Product Declaration* (EPD); 17/WG TC 59/SC 4 – *Environmental performance of buildings*; 17/WG TC 59/SC 5 – *Civil engineering*. Others subcommittees work on materials (SC 8), organization of information (SC 13) and functional requirements and performance (SC 14, SC 15, SC 16 and SC 17). In addition there is also a group directly under the technical committee named ISO/TC 59/SC 17 – *Sustainability in building construction,* which contributes to address sustainability in the context of buildings and civil engineering works. The new technical specification and standard published are:

- ISO/Guide 82:2014 [26]. Guidelines for addressing sustainability in standards. This Guide provides guidance to standards writers on how to take account of sustainability in the drafting, revision and updating of ISO standards and similar deliverables.
- ISO 15392:2008. *Sustainability in building construction* - *General principles* [27]. This International Standard presents the principles of sustainability connected to buildings and construction works. It is based on the concept of sustainable development applied to the life cycle of buildings and other construction works, from their inception to the end of life. It is applicable to buildings and construction works individually and collectively, as well as to materials, products, services and process related to the life cycle of the building.
- ISO/TR 21932:2013. *Sustainability in buildings and civil engineering works – A review of terminology* [28]. This Technical Report provides a compilation of terms

and definitions of concepts related to both construction and use of a building. It is referred also to civil engineering works and to the effect on sustainability, as applied in the documents of ISO/TC 59/SC 17 - Sustainability in buildings and civil engineering works. The previous review is the ISO/TR 21932:2006.

- ISO 21929-1:2011. *Sustainability in building construction - Sustainability indicators - Part 1*: Framework for the development of indicators and a core set of indicators for buildings [29]. This part of ISO 21929 provides the guidelines for the development of sustainability indicators related to the buildings. It defines also the aspects that must be taken into account when developing systems of sustainability indicators for new or existing buildings, related to their design, construction, operation, maintenance, refurbishment and end of life. Together, the core set of indicators provides measures to express the contribution of the buildings to sustainability.
- ISO/TS 21929-2:2015. *Sustainability in building construction - Sustainability indicators – Part 2*: Framework for the development of indicators for civil engineering works [30]. This part of ISO 21929 provides the guidelines for the development of sustainability indicators within the civil engineering works. It defines the impacts that these works have on developing systems of sustainability indicators.
- ISO 21931-1:2010. *Sustainability in building construction - Framework for methods of assessment of the environmental performance of construction works- Part 1*: Buildings [31]. This part of ISO 21931 provides a general framework for improving the quality and comparability of methods for assessing the environmental performance of buildings and their related external works within its site (curtilage).
- ISO 21930:2007. *Sustainability in building construction - Environmental declaration of building products* [32]. This Standard defines the principles and requirements for the environmental declarations of building products (EPD). Its complement is the ISO 14025:2006 – *Environmental labels and declarations – Type III environmental declarations – Principles and procedures.*

The technical committee ISO/TC 207 – *Environmental management*, is responsible for developing the ISO 14000 standards for environmental management. This set of regulations was launched to assist the sustainable development. The most recognized framework for environmental management systems (EMS) is the ISO 14001, which helps organizations to manage the impact of their activities on the environment. Other environmental management tools developed by ISO/TC 207 include:

- ISO 14004 series that provides an additional guidance to ISO 14001;
- ISO 14031 series that provides guidance on how the organizations can evaluate its environmental performance with performance indicators;
- ISO 14020 series that addresses a range of different approaches to environmental labels and declarations;
- ISO 14040 standards series that provides guidelines for the LCA systems.

The European CEN has established, on behalf of the European Commission in 2004, the technical committee CEN/TC 350 – *Sustainability of construction work*. It is responsible of the development of voluntary horizontal standardized methods for the assessment of new and existing construction and of the standards for the construction products.

It has been divided into seven work groups: CEN/TC 350: TG *Framework*; CEN/TC/WG1: *Environmental performance of buildings*; CEN/TC WG2: *Building life cycle description*; CEN/TC WG3: *Product Level* (EPD, communication formats etc.); CEN/TC WG4: *Economic Performance Assessment of Buildings*; CEN/TC WG5: *Social Performance Assessment of Buildings*; CEN/TC WG6: *Civil Engineering works*. The rules are listed below:

- CEN/TR 15941:2010. *Sustainability of construction works - Environmental product declarations- Methodology for selection and use of generic data* [33]. This technical report supports the development of Environmental Product Declarations (EPD). It supports in using generic data according to the core product category rules (prEN 15804) during the preparation of EPD for construction products, process and services in a consistent way. The requirements for the use of generic data are described below in prEN 15804.
- EN 15643-1:2010. *Sustainability of construction works - Sustainability assessment of buildings - Part 1*: *General framework* [34]. This European standard provides the general principles and requirements for the assessment of buildings in terms of environmental, social and economic performance. It takes into account technical characteristics and functionality. The framework can be applied to all types of buildings and it is relevant for the assessment of the environmental, social and economic performance of new buildings over their entire life cycle, and of existing buildings over their remaining service life and end of life stage.
- EN 15643-2:2011. *Sustainability of construction works - Assessment of buildings- Part 2: Framework for the assessment of environmental performance* [35]. This

standard provides the specific principles and requirements for the assessment of environmental performance of buildings under the general framework of EN 15643-1. The standards developed under this framework neither set the rules on how different building assessment schemes may provide valuation method, nor do they prescribe levels, classes or benchmarks for measuring performance. It excludes the assessment of building's influence on the environmental aspects and impacts of the local infrastructure beyond the area of the building site, and environmental aspects and impacts resulting from transportation of the users of the building. It also excludes environmental risk assessment.

- EN 15643-3:2012. *Sustainability of construction works- Assessment of buildings- Part 3: Framework for the assessment of social performance* [36]. The standard provides specific principles and requirements for the assessment of social performance of buildings taking into account technical characteristics and functionality of a building. The social performance are represented through indicators for the following social performance categories: accessibility, adaptability, health and comfort, loadings on the neighborhood, maintenance, safety/security, sourcing of materials and services, stakeholders involvement.
- EN 15643-4:2012. *Sustainability of construction works - Assessment of buildings - Part 4: Framework for the assessment of economic performance* [37]. This European standard provides specific principles and requirements for the assessment of economic performance of buildings taking into account technical characteristics and functionality. The evaluation of economical performance is one of the sustainability assessment aspects under the general framework of EN 15643-1. It includes economic aspects of a building relating to the built environment within the area of the building site. It excludes economic aspects beyond the area, such as economic impacts of local infrastructure and economic impacts resulting from transportation.
- EN 15804:2012 + A1:2013. *Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products* [38]. This European standard provides core product category rules (PCR) for Type III environmental declarations for any construction product and construction service. The core PCR: 1) defines the parameters to be declared and the way in which they are collated and reported; 2) describes which stages of a product's life cycle are considered in the EPD and which processes are to be included in the life cycle stages,

3) defines rules for the development of scenarios; 4) includes the rules for calculating the Life Cycle Inventory (LCI) and the Life Cycle Impact Assessment (LCIA) underlying the EPD, including the specification of the data quality to be applied; 5) includes the rules for reporting predetermined, environmental and health information, which is not covered by LCA for a product, construction process and construction service; 6) defines the conditions under which construction products can be compared, on the basis of the information provided by EPD.

- EN 15942:2011. *Sustainability of construction works - Environmental product declarations- Communication format business-to-business* [39]. This standard is applicable to all construction products and services related to buildings and construction works. It specifies and describes the communication format for the information defined in FprEN 15804 for business-to-business communication to ensure a common understanding through consistent communication of information.
- EN 15978:2011. *Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method* [35]. This European standard specifies the calculation method, based on LCA and other quantified environmental information, to assess the environmental performance of a building, and gives the means for the reporting and communication of the outcome. The standard is applicable to new and existing buildings and to refurbishment projects. The standard gives: (1) the description of the object of assessment, (2) the system boundary that applies at the building level, (3) the procedure to be used for the LCI, (4) the list of indicators and procedures for the calculations of these indicators, (5) the requirements for presentation of the results in reporting and communication, and (6) and the requirements for the data necessary for the calculation.
- EN 16309:2014+A1:2014. *Sustainability of construction works – Assessment of social performance of buildings – Calculation methodology* [40]. The standard provides specific methods and requirements for the assessment of social performance of a building. It takes into account the building's functionality and technical characteristics. This European standard applies to all types of buildings, both new and existing. In this first version of the standard, the social dimension of sustainability concentrates on the assessment of aspects and impacts for the use stage of a building expressed using the following social performance categories (from EN 15643 3): (1) accessibility, (2) adaptability, (3) health and comfort, (4) impacts on the

neighborhood, (5) maintenance, and (6) safety and security.

- EN 16627:2015. *Sustainability of construction works – Assessment of economic performance of buildings – Calculation methods* [41]. This European standard specifies the calculation methods, based on Life Cycle Costing (LCC) and other quantified information. It assesses the economic performance of a building and gives the means for the reporting and communication of the outcome of the assessment.
- prEN 15643-5. *Sustainability of construction works – Sustainability assessment of buildings and civil engineering works – Part 5: framework on specific principles and requirements for civil engineering works* [38]. This European standard is targeted to cover specific principles and requirements for the sustainable assessment of civil engineering works in addition to the general framework. The main objective is to ensure that the specific principles and requirements for the sustainable assessment of civil engineering works are identified and taken into account.

1.4 Benchmarking process

An important step to evaluate the achievement of the targets in the environmental issues is the quantification of contribution given by the human activities with an environmental impact. Defining the targets is necessary for binding the minimum requirements to be met and making possible the development of a sustainable society. Nevertheless, the specific environmental loads, resulting from construction, maintenance and operation of buildings, need to be specified.

In this meaning, we can define the term benchmark as referred to establish building target used for the comparison of buildings with similar characteristics. They are variable from country to country, according to statistical values and political target values.

The benchmarking process consists of four stages [42]. First of all it is necessary to categorize in a database, by building type and size, the energy performance of a consistent number of buildings. Second, the necessary information is collected to evaluate the performance for the examined building. The third stage, the more relevant, consists in comparing the building performance with the sample held in the database, for quantify the quality of the building in terms of performance. The final stage is aimed at improving this performance. Figure 7 shows the steps just described.

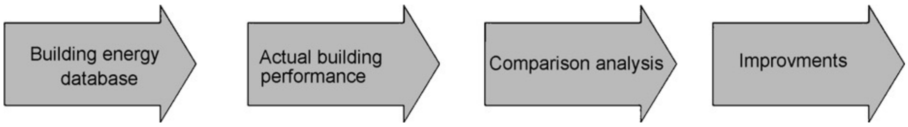

Figure 7 Building energy benchmarking process [42].

The current rules available, in particular the ISO 21931-1 – *Framework for methods of assessment of the environmental performance of construction works*, do not set any reference value or procedure for the benchmarking process.

In order to apply this procedure to the building assessment, it is necessary to establish a scoring scale. This scale has the aim of evaluating the target achieved on a scale in which the zero is generally the minimum acceptable performance. The reaching of a value lower than zero means that the building does not comply minimum performance admissible. The following level compared with zero corresponds respectively to the state of the art, without any improvement effort, and the best practice value, reachable with advanced performance compared with the running procedure. The latter level is related to technological improvements and experimentation, then ever evolving. The last level consists in the upper limit of the scale and is the highest theoretically possible level.

One of the most common benchmarking processes can be applied to the energy performance. Basically it consists of a comparison of the energy performance index (EPI) of a building with a sample of similar buildings. A common EPI used is the annual energy consumption per unit area but, depending on the performance type that needs to be evaluated, other indicators may also be used [43].

This benchmark scale is widely used in both LCA method and criteria method used for assess the sustainability performance in the building sector.

Conclusions

In this chapter we dealt with some aspects of sustainability. Starting from the general concept we have focused on each aspect that contributes to understand its development and the context in which it can be applied.

Since the Brundtland's definition, which highlights the "needs of future generations" without giving any further detail, many improvements have been made in defining which are the aspects that play a role in the sustainability evolution: environment, society and economy. The balance of these three elements, which are mutually influenced, is essential in order to make sustainable the overall development.

Since the Industrial Revolution, the demographic growth has been on average 1.3 % per year. This phenomenon, linked with a request for a higher standard of living, has led to increase the levels of CO_2 and to exploit resources beyond the allowed limits. Past trends suggest that GHG emissions are likely to continue to increase. The exact rate cannot be predicted but, between 1970 and 2010, emissions increased of 79 %, from 27 Gt to over 49 Gt of GHG [7]. To limit the damage is necessary to give an appropriate response to the climate change by evaluating and developing all the available tools, such as:

- To address the climate change policies in order to reach the short-term and long-term objectives, including the goal of reaching 450 ppm of CO_2eq by the end of the 21st century. The national policies can affect future trajectories of GHG emissions both directly and indirectly through policies affecting economic growth and energy consumption;
- To promote a sustainable technological development, decreasing the costs of new technologies in order to bridge the delay of the society in their acceptance. Such delay, together with the exponential growth, may cause a fast consumption of the available resources;
- To implement technologies that do not involve the use of fossil fuels for the production of primary energy, supporting the options that are energy-efficient and less dependent from non-renewable sources;
- To better define the concepts related to sustainability by spreading knowledge: lack of knowledge means lack of sustainable development. The choice between the various mitigation options is related to the behavior of the "human capital". It acts according to awareness and understanding of the consequences of climate change;
- To improve the cost of mitigation technologies with the aim of facilitating the spread on the large scale and thus reduce the impact of the transformation on developing countries.

Chapter 2

Overview on environmental assessment schemes

This chapter provides an overview of the environmental assessment schemes available on the market. The fundamental distinction between the Life Cycle Assessment (LCA) and multi-criteria decision making systems has been carried out, these being the two main approaches to the design of the environmental assessment tools. Through the use of graphs and tables the diffusion of assessment schemes in the various countries of the world is investigated and the data about their release on the market are provided, showing the trend from 1990 to 2014.

2.1 Life Cycle Assessment method

The Life Cycle Assessment is a method for examining the whole environmental impact of a product throughout its life, from manufacturing, passing trough use, to its end of life. This procedure of evaluation, 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. In the building sector the LCA has been used since 1990 and the introductory part of international standard ISO 14040 [44] states: "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".*

LCA is therefore a systematic analysis that, in some cases, can be used to evaluate the alternatives for environmental improvement as a support for the decision-making. The boundaries of the building LCA can be of three types: cradle-to-grave, cradle-to-gate or gate-to-gate.

The *cradle-to-gate* is an assessment analysis of a partial product life cycle, from resource extraction to the factory gate, before the transport to the consumer. The *cradle-to-gate* approach not involves the use phase and the disposal phase and it is usually used as basis for the EPD [45]. The *gate-to-gate* is a partial analysis that looks at only one process in the entire production chain. The information of each *gate-to-gate* module can be linked accordingly in a production chain, including the extraction of raw materials, transportation, disposal, 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, manufacturing and transportation to site, and terminates with the end of life (EOL) phase, including demolition, recycling potential, landfill and re-use [46].

The idea of the *cradle-to-grave* process, typical of the LCA methods, is illustrated in a simplified way in Figure 8. In general, this process is more difficult and complex than the one shown in the figure, since each building is deeply different and with unique features with respect to the others, i.e. diverse materials, production method and construction process.

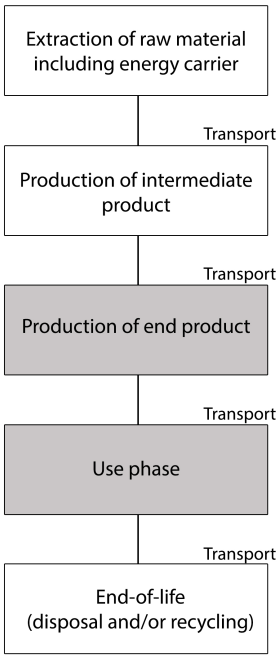

Figure 8 Simplified life cycle of a product. Source: [47].

The development of LCA method started in the early 1970s and the increasing interest in Europe and North America led to a pair of conferences considered as the starting point for a new development: the workshops of the Society of Environmental Toxicology and Chemistry (SETAC), which took place in 1990 respectively in Smugglers Notch (Vermont) and in the Belgian University of Leuven.

The first SETAC attempt in defining the LCA structure was in 1990, followed by a second attempt in 1993. Figure 9 shows the structure differences between the two schemes proposed by SETAC.

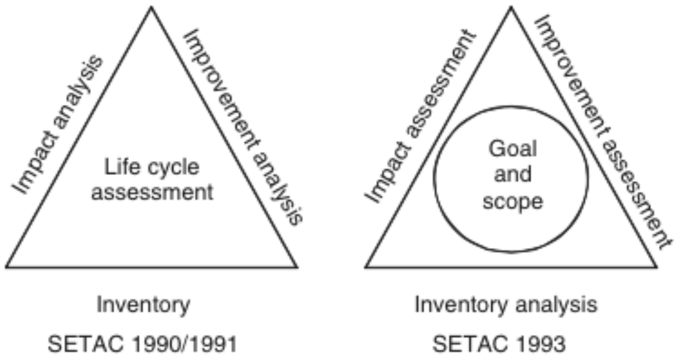

Figure 9 The SETAC-triangle in LCA guidelines. Source: [47]

In the SETAC triangles (Figure 9), we can recognize the three steps of the LCA: (1) Inventory or Inventory analysis, (2) Impact analysis or Impact assessment, and (3) Improvement analysis or Improvement assessment.

The first step of the Life Cycle Inventory (LCI) analysis is defined by the ISO standard 14040:2006 [48] as the "*phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its entire life cycle".* According to Klöpffer [47], it is an analysis based on simplified linear systems, which takes into account all the parameters of the system from cradle to grave. In Figure 10, Source: [17, 18]. an example with its system inputs and outputs is tabulated.

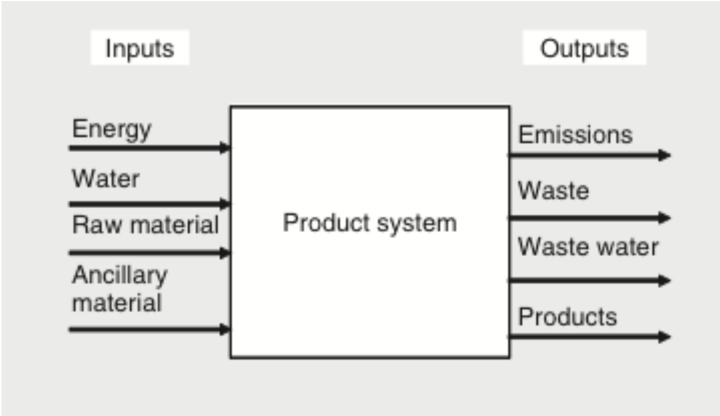

Figure 10 Analysis of matter and energy of a product system. Source: [47].

The second stage, the *Impact analysis,* provides an ecological investigation trough the weighting of the system elements, with the aim of evaluating the significance of the potential impact on the environment during the whole the life cycle of the product. The processes evaluated in this stage are related to: materials, determining the type and the quantity used for the building; transport, calculating the distance between the manufacturer and the building site; construction, contributing in low part to the environmental impact due to the waste generated during the process, estimated around 5 % [49-51]; operation and maintenance, consisting in operating energy and maintenance work for the building; end of life phase, significant for the potential recycling of materials that might decrease the environmental impact.

The last phase, the *Improvement analysis,* is basically an interpretation of the data conducted according to specific rules. These rules were modified during the standardization process of ISO in the 1996 that led to an LCA structure slightly different from the SETAC one.

The new structure of the international standard differs from the previous not in significant way, even though the LCA phases have been renamed as follows:

- Goal and Scope Definition,
- Life Cycle Inventory Analysis,
- Life Cycle Impact Assessment,
- Interpretation.

The definition of the goal and scopes has the aim of setting the purpose, the audiences and the system boundaries that determine the processes to be included within the LCA. An important parameter to notice, with a significant impact on the results of LCA research, is the building lifespan, especially for the total energy consumption during the use phase. For residential building, the lifespan is quoted between 40÷100 years, for commercial buildings is quoted between 40÷75 years but, in both cases, 50 years were commonly used as a standard building lifespan [49].

2.2 Multi-criteria decision making methods

During the last 20 years, environmental assessment schemes have had a great development. The common tendency has been to establish an objective and comprehensive method for assessing a broad range of environmental performance. The aim of these schemes is to measure the performance of a building in a consistent manner, with respect to pre-established standards, guidelines, factors, or criteria [52].

The Multi-Criteria Decision Making Methods are intended to evaluate building performance through frameworks based on the following major components listed below:

- The *categories*: a specific set of the environmental performance taken into account during the assessment;
- The *scoring:* sum of the number of possible points or credits that can be earned achieving a fixed level of performance in several issues analyzed;
- The *weighting system:* represents the relevance assigned to each specific category within the overall measure of performance;
- The *output:* means of showing in a comprehensive manner the results of the environmental performance obtained during the scoring phase.

This structure is the same for each scheme but, going into the details, it diverges in significant parts. This subject will be widely discussed in the Chapter 2, in which the most common assessment tools currently available on the market are illustrated and discussed.

2.3 General description of the environmental assessment schemes in the world

Generally, the aim of environmental assessment schemes is to assist the design process evaluating the performance of a building through a set of criteria. These indicators, appropriately weighted, evaluate the impact of the building sector on the environment helping in the decision making process. According to Cole [53], defining in a comprehensive and univocal way what “building performance” means is quite hard because of the different interests and requirements of the actors involved in this sector. For this reason, many organizations and research groups have contributed to develop different indicators to suite the needs of each stakeholders. The building performance can be defined as the outcome of how successfully a building process performs a given task or function. A wide number of assessment tools have reached a considerable success during the past years in order to evaluate in comprehensive way the outcomes of the building performance. They were developed for building components or whole buildings, covering their entire life cycle or just a part of it.

The Building Research Establishment Environmental Assessment Method (BRREAM) was the first scheme introduced to assess the environmental impact of a building. It was introduced in in 1990 and, since then, the environmental assessment field has been subject to a rapid increase of the number of systems developed and introduced on the market worldwide. This phenomenon seems to having reached stabilization in the last few years (Figure 11).

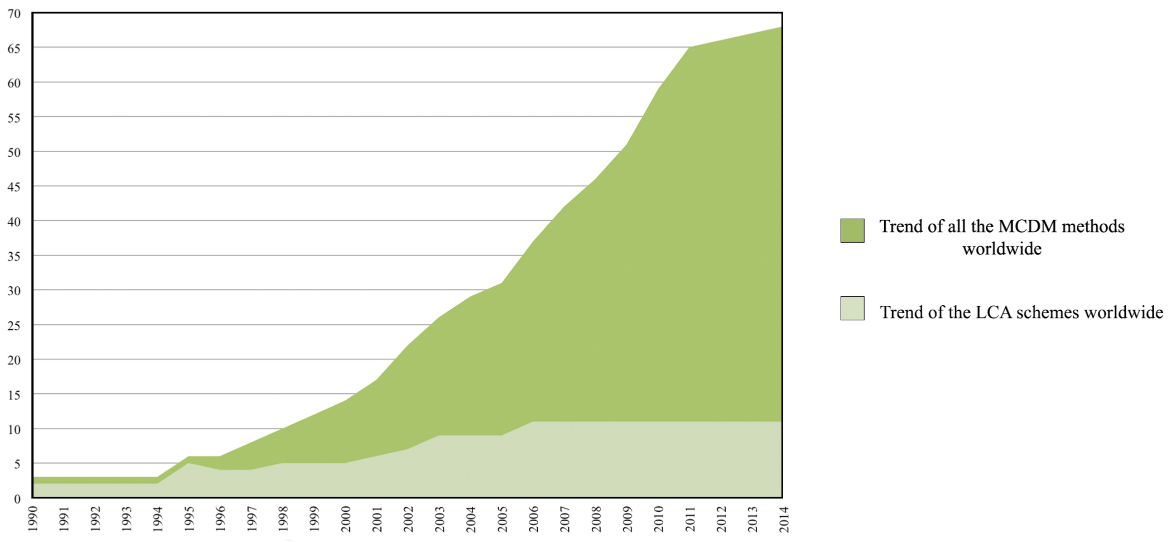

Figure 11 Trend of the assessment schemes worldwide from 1990 to 2014.

The highest rate of introduction of new schemes has been registered between 1994 and 2011. In the latter period, the trend of worldwide schemes, driven by the multi-criteria decision making methods, which constitute the main part, has been essentially linear. Conversely, the trend of the LCA tools is characterized by several discontinuities. Moreover no new LCA tool has been introduced since 2006. Regarding the multi-criteria decision making systems, in addition to the aforementioned linearity we can notice that after the introduction of BREEAM in 1990, a five years gap has occurred until 1996. A marked reduction of the rate of development of new tools started in 2011.

More in detail, Table 1 lists all the systems released worldwide, including both LCA schemes and the Multi-Criteria Decision Making methods. The distinction between LCA and Multi-Criteria Decision-Making schemes is marked; the table also shows additional information about the year in which these schemes were delivered on the market. In some cases this information was not available and therefore it will be omitted.

Table 1 Building environmental assessment methods and tools in use worldwide. Adapted from [54].

Region	Country	Name	Owner/Management	Year	Type of method	References
Africa	South Africa	Green Star SA	South Afica GBC	2008	MCDM	[55] [54]
		SBAT	CSIR	2002	MCDM	[56, 57]
Asia	China	GHEM	China Real Estate Chamber of Commerce	N/A	MCDM	[54]

Region	Country	Name	Owner/Management	Year	Type of method	References
		GOBAS	Ministre of Science & Technology	2003	MCDM	[54, 58]
		DGNB	DGNB China	2009	MCDM	[54, 59, 60]
		ESGB	Ministry of Housing and Urban-Rural Construction	2006	MCDM	[54, 61]
	Hong Kong	BEAM Plus	HK-BEAM Society	1996	MCDM	[54, 62]
		CEPAS	HK Building Department	2002	MCDM	[54]
	India	TERI-GRIHA	TERI (The Energy & Research Institute)	2007	MCDM	[54, 63]
		LEED®-India	Indian GBC	2011	MCDM	[54, 63, 64]
	Japan	CASBEE	Japan Sustainable Building Consort.	2004	MCDM	[65, 66]
	Korea	GBCC	Korean Korea Institute of Energy Research	1997	MCDM	[67]
	Singapore	Green Mark	Singapore Building & Construction Authority (BCA)	2005	MCDM	[68]
	Taiwan	EEWH	ABRI (Architecture and Building Research Institute)	1999	MCDM	[69]
	Thailand	DGNB	ARGE - Archimedes Facility - Management GmbH, Bad Oeynhausen & RE / ECC	2010	MCDM	[60]
	Vietnam	LOTUS	Vietnam GBC	2007	MCDM	[70]
Europe	Austria	BREEAM AT	DIFNI	N/A	MCDM	[71]
		DGNB	ÖGNI	2009	MCDM	[60]
	Belgium	LEnSE	Belgian Building Research Institute	2008	MCDM	[54]
	Bulgaria	DGNB	Bulgarian GBC	2009	MCDM	[60]
	Czech Republic	DGNB	DIFNI	2011	MCDM	[60]
		SBToolCZ	iiSBE International, CIDEAS	2010	MCDM	[72]
	Denmark	BEAT 2002	SBI	2002	MCDM	[14, 73]
		DGNB	Denmark GBC	2011	MCDM	[59, 60]
	Finland	PromisE	VTT	2006	MCDM	[54]
		BeCost	VTT	N/A	MCDM	[14]
	France	HQE™ Method	HQE™	1997	MCDM	[54]
		ELODIE	CSTB's Environment Division	2006	LCA	[54]
		TEAM™	Ecobilan	1995	LCA	[14, 74]
		EQUER	Ècole des Mines de Paris, Centre d'Énergétique et Procédés	1995	LCA	[14, 74]
		ESCALE	CSTB and the University of Savoie	2001	MCDM	[14, 75]
		PAPOOSE	TRIBU Architects	N/A	LCA	[14, 74]
	Germany	DGNB	German Sustainable Building Council	2008	MCDM	[60]
		BREEAM DE	DIFNI	2011	MCDM	[71]
		GABI	IKP University of Stuttgart, PE Product Engineering GmbH	1990	LCA	
		LEGEP®		2001	LCA	[14]

Region	Country	Name	Owner/Management	Year	Type of method	References
	Greece	DGNB	DIFNI	2010	MCDM	[60]
	Hungary	DGNB	DIFNI	2010	MCDM	[60]
	Italy	LEED® Italia	Italiy GBC	2006	MCDM	[76]
		Protocollo ITACA	iiSBE Italia	2004	MCDM	[54]
	Luxembourg	BREEAM LU	DIFNI	2009	MCDM	[71]
	Netherlands	BREEAM-NL	Dutch GBC	2011	MCDM	[54, 71, 77]
		SIMAPRO	Pre Consultants	1990	LCA	[78]
		Eco-Quantum	IVAM	2002	LCA	[14]
	Norway	BREEAM-NOR	Norwegian GBC	2012	MCDM	[14, 71]
		Økoproifl	SINTEF	1999	MCDM	[79]
	Poland	DGNB	DGNB International	2013	MCDM	[60]
	Portugal	LiderA	Instituto Superior Técnico, Lisbon	2005	MCDM	[54]
		SBToolPT	iiSBE Portugal, LFTC-UM, ECOCHOICE	2007	MCDM	[80]
	Russia	DGNB	DGNB International	2010	MCDM	[60]
	Spain	VERDE	Spanish GBC	2006	MCDM	[54]
		DGNB	N/A	2011	MCDM	[60]
		BREEAM ES	Fundacion Instituto Technològico de Galicia	2010	MCDM	[71]
	Sweden	EcoEffect	Royal Institute of Technology	2006	LCA	[14, 54, 73]
		BREEAM SE	Swedish GBC	2008	MCDM	[71]
	Switzerland	BREEAM CH	DIFNI	N/A	MCDM	[71]
		DGNB	SGNI	2010	MCDM	[60]
	Turkey	DGNB	-	2010	MCDM	[60]
	Ukraine	DGNB	DGNB International	N/A	MCDM	[60, 81]
	United Kingdom	BREEAM	BRE	1990	MCDM	[14, 71, 82]
		Envest 2	BRE	2003	LCA	[14, 83]
North America	Canada	LEED®-Canada	Canada GBC	2009	MCDM	[54, 84]
		GreenGlobes	ECD Canada	2000	MCDM	[54, 85]
		ATHENA™	ATHENA Sustainable Material Institute	2002	MCDM	[14, 83, 86]
	Mexico	SICES	Mexico GBC	N/A	MCDM	[54]
	United States	LEED®	United States GBC	1998	MCDM	[14, 54]
		BEES 4.0	NIST	1998	LCA	[14, 83, 87]
		GreenGlobes	Green Building Initiative	2004	MCDM	[54, 85]
Oceania	Australia	Green Star	Austalian GBC	2003	MCDM	[88, 89]
		NABERS	NSW Office of Environment and Heritage	2001	MCDM	[90, 91]
	New Zealand	Green Star NZ	New Zealand GBC	2007	MCDM	[92, 93]
South America	Argentina	LEED®-Argentina	Argentina GBC	N/A	MCDM	[94, 95]
	Brazil	LEED®-Brazil	Brazil GBC	2007	MCDM	[96, 97]
		HQE™	Fundação Vanzolini	2014	MCDM	[98]

Region	Country	Name	Owner/Management	Year	Type of method	References
Generic		SBTool	iiSBE	2002	MCDM	[80, 99]
		SPeAR	Ove Arup Ltd.	2000	MCDM	[100]

From Table 1 we can infer the distribution of the tools: 45 for Europe, 14 for Asia and 7 for North America. Both Oceania and South America have 3 systems but, in the second case, they are just a customization of other frameworks originally developed in other countries. There are only two frameworks, which are not associated to any specific country.

Focusing on the European countries, we can see that the ones with the largest number of schemes is France with six schemes. Beside France, the countries that have the largest number of systems are Germany and China, each one with 4 available schemes.

Figure 12 allows us to have a geographical distribution of the number of environmental assessment schemes per country. The number of systems in Africa and Middle Eastern countries is close to zero, while the majority of available systems is found in the European countries.

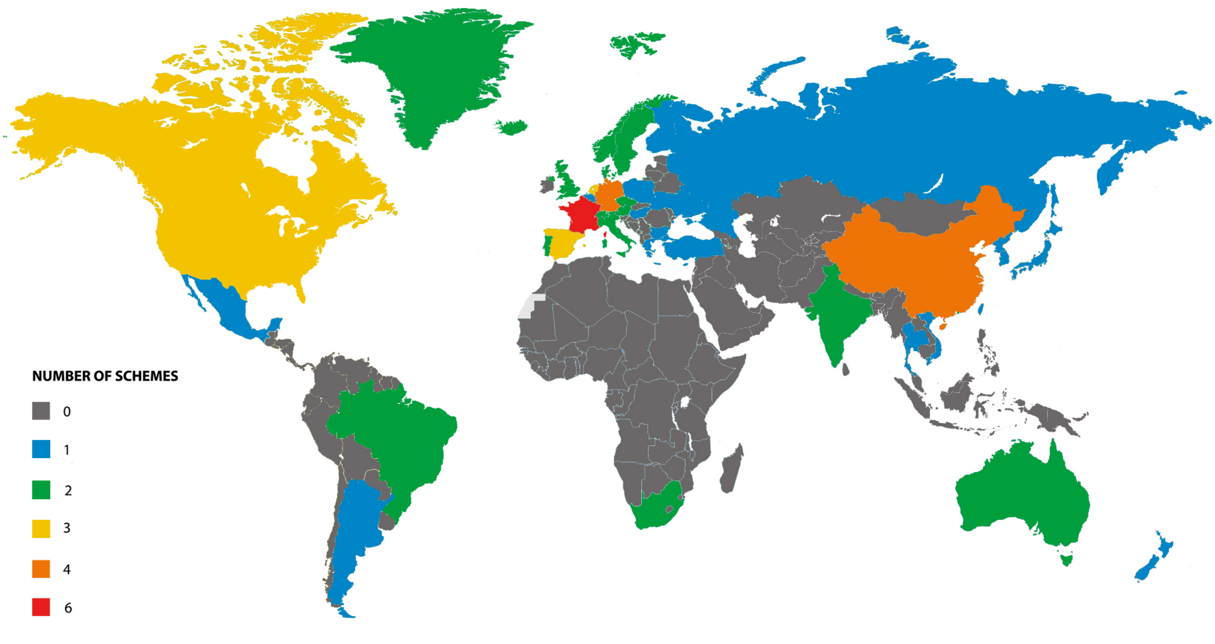

Figure 12 Number of schemes available worldwide.

For the goal of this survey, an array of assessment tools has been selected from a wide and heterogeneous set of and heterogeneous set of sources. Focusing on Multi-Criteria Decision Making methods, the main purpose was main purpose was to cover the schemes that have with the most widespread use and that most frequently appear frequently appear in the literature. We have selected tools from different parts of the world, excluding from the excluding from the analysis the tools that are not completely developed and attempting to cover a broad range of cover a broad range of assessed categories and evaluation criteria. In particular, the next chapter is devoted to the chapter is devoted to the detailed presentation of six schemes: Building Research Establishment Environmental Establishment Environmental Assessment Methodology (BREEAM, United Kingdom), Comprehensive Comprehensive Assessment System for Built Environment Efficiency (CASBEE, Japan), Deutsche Gesellschaft Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB, Germany), Haute Qualité Environnementale (HQE™, Environnementale (HQE™, France), Leadership in Energy and Environmental Design (LEED®, United States) (LEED®, United States) and SBTool (International). An overview of such selection of schemes is presented

schemes is presented

Table 2.

Table 2 Selection of environmental assessment tools

Assessment tool	Launch year	Launch country	Certification body	International version	Weightings	Rating levels
BREEAM	1990	U.K.	BRE	- International Version: New Construction, Refurbishment, In-Use, Communities Bespoke.	Applied to each category	Pass, Good, Very Good, Excellent, Outstanding
BREEAM Norway	2012	Norway	NGBC	N/A	Applied to each category	Pass, Good, Very Good, Excellent, Outstanding
CASBEE	2004	Japan	JSBC	N/A	Highly complex weighting system applied at every level	S/ A/ B+/ B-/ C
DGNB	2008	Germany	DGNB	- International Version: Core 14 - National Version: Argentina, Austria,	Applied to each category	Certified, Bronze, Silver, Gold
HQE	1997	France	Certivèa, Cerqual, Cèquami, Cerway	HQE for Building Under Construction, HQE for Building in Operation, HQE for Urban Planning and Development	N/A	Pass, Good, Very Good, Excellent, Exceptional
Itaca Protocol	2004	Italy	iiSBE Italia	N/A	Applied to each category	-1/ 0/ 1/ 2/ 3/ 4/ 5
LEED	1998	U.S.A.	USGBC	N/A	All credits are equally weighted but de facto the number of credits related to each issue is weighted	Certified, Silver, Gold, Platinum
SBMethod	2002	International	iiSBE	SBToolCZ (Czech Republic), SBToolPT (Portugal), Protocollo Itaca (Italy), Verde (Spain)	Applied to each category	-1/ 0/ 3/ 5

Conclusions

In this chapter we have proposed a general description of the released schemes worldwide, which have been separated according to the distinction between LCA and Multi-Criteria Decision-Making schemes. It is worth to note that LCA methods, even though they are more accurate in the assessment process as they obey to the *cradle-to-grave* principle and include also indirect factors in the performance evaluation, have encountered a limited success compared to Multi-Criteria Decision-Making method. This has been likely caused by their highly elaborated structure that makes them potentially more efficient but, at the same time, more difficult to be practically implemented.

In conclusion, we can state the following considerations:

- The largest concentration of systems can be found in Europe and in particular in France, where the number of schemes comprising LCA and multi-criteria decision making schemes amount to 6. Moreover, the first systems to have been released in 1990 were European: GABI (Germany), SimaPro (Netherlands) and BREEAM (United Kingdom).
- No assessment tool has been developed nor adopted in Middle Eastern and African countries (except for South Africa, where a customized version of Green Star is available). A very limited utilization of environmental assessment tools can be observed also in South America, where only Chile and Brazil have adopted customizations of schemes developed abroad. A possible reason for this poor interest for the environmental sustainability is given by the political and economical instability of such countries.
- The general trend of multi-criteria decision-making systems, as illustrated in Figure 11, is essentially linear between 1996 and 2011. The trend of LCA methods is instead characterized by several discontinuities and by a complete break in 2006: this is probably caused by the aforementioned complications of this class of methods.

Chapter 3

A selection of multi-criteria decision making methods

The six selected assessment tools (see

Table 2) are described in this chapter. Exploiting categories, scoring, weighting and outputs, the structure and the main features of each system are presented. The information gathered constitute the basis of the analysis that will be performed in the remaining part of the thesis and that represents the core of this study. The final part of the chapter is devoted to the presentation of the major local customizations.

3.1 Building Research Establishment Environmental Assessment Methodology

Conceived in the U.K. in 1988 by the Building Research Establishment (BRE), the Building Research Establishment Environmental Assessment Methodology (BREEAM) was launched in 1990. Currently it has around 425.000 certified building all around the world and two million registered for assessment since its launch in 1990. There is a national version, specifically developed for England, and also schemes released for specific countries, such as the United Kingdom, Germany, Netherlands, Norway, Spain, Sweden and Austria. It also features an international system, namely BREEAM International, to be used by countries that do not have their own specific system. It is to be noticed that, whenever a country has its specific national scheme fitting the building type, this must be applied instead of the BREEAM International. The schemes currently available are reported in

Table 3.

Table 3: BREEAM schemes currently available

Generic Schemes	**Specific Schemes**	**Management**
International	BREEAM International for New Construction 2013 BREEAM International Refurbishment & Fit-Out BREEAM In-Use International 2013 BREEAM Communities Bespoke International 2010	Green Building Council
UK	BREEAM UK New Construction 2014 BREEAM UK Communities 2012 BREEAM In-Use 2013 EcoHomes 2006 Code for Sustainable Homes 2010 BREEAM UK Refurbishment 2012	UK Green Building Council

Generic Schemes	Specific Schemes	Management
Germany	BREEAM DE Bestand	DIFNI
Netherlands	BREEAM NL	Dutch Green Building Council (DGBC)
Norway	BREEAM NOR	Norwegian Green Building Council (NGBC)
Spain	BREEAM ES	Fundacion Instituto Technològico de Galicia
Sweden	BREEAM SE	Swedish Green Building Council (SGBC)
Austria	BREEAM AT In-Use	DIFNI
Switzerland	BREEAM CH	DIFNI
Luxembourg	BREEAM LU	DIFNI

The BREEAM International provides a set of environmental assessment methods that contain all stages of a building lifecycle. In particular BREEAM for New Construction can be applied to assess new commercial and residential buildings, during the design and the construction stages. The buildings that fall outside the standard scheme require the development of bespoke criteria that are well adaptable to individual projects. The BREEAM In-Use is a scheme mainly oriented to managers, investors, owners and occupiers for reducing the running costs and aims to assess the environmental performance of the existing non-domestic buildings. Among the UK schemes, we can find other two environmental assessment methods, specifically developed for England, Wales and Northern Island: *EcoHomes* and the *Code for sustainable homes*. EcoHomes was launched in 2000 and became mandatory for social housing in 2003 with over 200.000 homes certified. In April 2007 it was replaced by the Government's scheme Code for sustainable homes. In Scotland the EcoHomes 2006 system is still in use [101].

The scheme is composed of ten categories describing sustainability with 71 total criteria. A percentage weighting factor is assigned to each category, and the overall amount 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 CO2, Water and Waste, which are reported in

Table 4 the categories for each scheme are listed.

Table 4 BREEAM: Categories for each scheme

Scheme's name	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
BREEAM UK Communities										•	•	•	•	•	
BREEAM UK New Construction	•	•	•		•	•	•		•				•	•	•
BREEAM In-Use	•	•	•		•	•	•		•				•	•	•
BREEAM Refurbishment	•	•	•		•	•	•		•				•	•	•
EcoHomes	•	•	•		•	•	•		•				•	•	•
Code for Sustainable Homes	•	•	•	•	•	•	•	•	•						

It must be noticed that in BREEAM UK Communities and in the Code for sustainable homes there are some significant differences.

The institute in charge of assessing the environmental credentials of a building is BRE, assigning a percentage value to the building performance by means of the rating scale in

Table 5.

Table 5 BREEAM: rating scale

Assessment level	**Scoring Scale (%)**
Outstanding	X ≥ 85
Excellent	70 ≤ X < 85
Very Good	55 ≤ X < 70
Pass	30 ≤ X < 55
Unclassified	X < 30

Note that there are additional criteria for achieving a BREEAM outstanding rating.

A further update has been BREEAM New Construction (2011) whose latest version is BREEAM UK New Construction, delivered in May 2014. In support to the BREEAM assessment scheme, but also to the EcoHomes and The Code for Sustainable Homes, the BRE provides the Green Guide to Specification as a guidance to designers and specifiers on the environmental impact of buildings and their construction materials[102]. It is an extensive, but not complete, catalogue of the most common building materials, containing more than 1.500 specifications used in various types of buildings. The ratings are based on Life Cycle Assessment, using the Environmental Profile Methodology[103].

3.2 Comprehensive Assessment System for Built Environment Efficiency

The Comprehensive Assessment System for Built Environment Efficiency, usually referred with the acronym CASBEE, is the only Japanese rating system, it was developed in 2001 by the Japan Sustainable Building Consortium (JSBC), which is a non-governmental organization comprising the Japanese government, academic partners and industry [104]. Then, in 2005, it was launched in international market as one of the second generation of assessment methods [105], and, since 2011, it has become mandatory in 24 Japanese municipalities.

The different assessment tools developed since the 2001 depending on the size of the building subject. The tool comes out with four available basic rating systems, one for each building life phase:

1. CASBEE for Pre-Design, used for the site selection and building planning;
2. CASBEE for New Construction to be used during the first three years since the building construction;
3. CASBEE for Existing Building, to be used after at least one year of life;
4. CASBEE for Renovation.

To fulfill the specific purposes, CASBEE features also a huge batch of rating schemes that are relevant when the basic version cannot be used, such as: Detached Houses, Temporary Constructions, Heat Island Effect, Urban Development, Cities and Market Promotions. Moreover, simplified Brief versions are available and can be completed in a short time span: these are usually used for achieving goals in the early stages of building projects. Lastly the local government versions are used in Nagoya, Osaka and Yokohama and they are fitted changing the coefficients weight.

The overview of the “CASBEE Family”, the way in which are collectively called the systems, is reported in Table 6.

Table 6 CASBEE: Structure of the CASBEE Family

Type of system	Type of project			
	New Construction	**Existing Buildings**	**Renovation**	**Other**
Housing System	CASBEE for Detached House (2014) CASBEE for Dwelling Unit (2014)	CASBEE for Detached House (2011): - CASBEE *for Housing Health Check List*		
Building System	CASBEE for Building (2014): - CASBEE *for Temporary Construction (2008)* *- CASBEE for Municipality (2010)* *- CASBEE for School*	CASBEE for Building (2014): - CASBEE *for Municipality (2010)* - CASBEE *for School*	CASBEE for Building (2014): - CASBEE *for Municipality (2010)* - CASBEE *for School*	
Urban System				CASBEE for Urban Development (2014): - CASBEE *for Community Health Checklist (2013)*
City Sistem				CASBEE for Cities (2013)

The CASBEE was developed to evaluate all the steps in the architectural design process:

- **Pre-Design**: this is the preliminary step in which all the background conditions are considered, such as natural, social, cultural and business. They are investigated for identifying the design process to follow;
- **Design**: in this step the background conditions recognized in the pre-design process are analyzed from a design viewpoint in order to define their ecological, technical, social, cultural, aesthetic and economic aspects. This phase attempts to integrate the design with the practice;
- **Post-Design**: the last step consists of an overall verification through the building life cycle, to evaluate the sustainability and to improve the design.

The tool comes out with four available basic rating systems, one for each building life phase: CASBEE for Pre-Design, used for the site selection and building planning; CASBEE for New Construction to be used during the first three years since the building construction; the CASBEE for Existing Building, to be used after at least one year of life and CASBEE for Renovation. To fulfill the specific purposes CASBEE features also a huge batch of rating schemes that are relevant when the basic version cannot be used, such as: Detached Houses, Temporary Constructions, Heat Island Effect, Urban Development, Cities and Market Promotions. Moreover, simplified Brief versions are available and can be completed in a couple of hours: these are usually used for achieving goals in the early stages of building projects. Lastly the local government versions are used in Nagoya, Osaka and Yokohama and they are fitted changing the coefficients weight.

CASBEE assesses a building project using a metric called Building Environmental Efficiency (BEE), which is given by the ratio between the *Built environmental quality* (Q), and the *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” [106]. Q and LR are computed on the bases of three sub categories, tabulated on a score sheet, reported in

Table 7.

Table 7 CASBEE: 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

The values got in each category are represented on a radar chart. The Assessment Results Sheet analyses and weights, using the coefficients for each item, the Q and LR value and produces, as last step, an overall score conveyed through the BEE index [107].

This index is necessary to assess the six category provided for the CASBEE evaluation: Indoor environment, Quality of Service, Outdoor environment (On-Site), Energy, Resources and Materials, and Off-site Environment. The ratios between Q and L are represented in Figure 13, where L and Q coincide respectively with the x and the y axis.

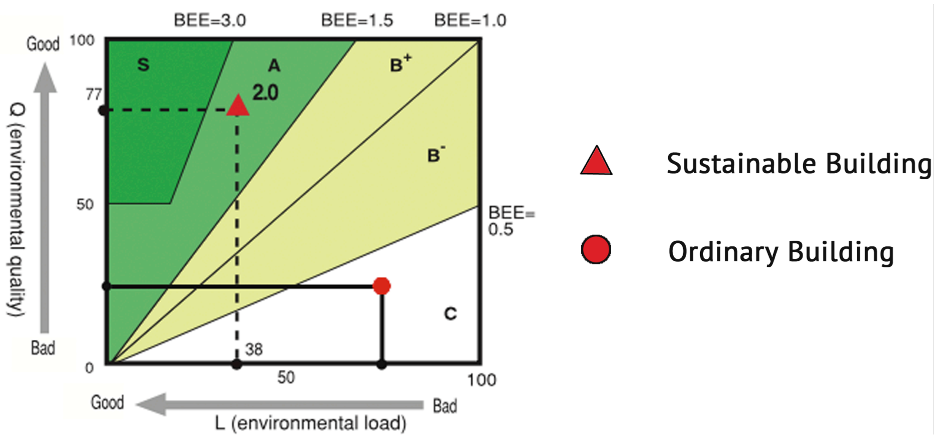

Figure 13 CASBEE: definition of the BEE and graph [108].

As we can read from Figure 13 the CASBEE assessments are ranked in five grades listed in Table 8.

Table 8 CASBEE: Scoring scale, assessment level and BEE value

Scoring Scale	**Assessment Level**	**BEE value**
S	Excellent	X > 3.0[a]
A	Very Good	1.5 ≤ BEE < 3.0 or X > 3.0[b]
B+	Good	1.0 ≤ BEE < 1.5
B-	Fairy Poor	0.5 ≤ BEE < 1.0
C	Poor	BEE < 0.5

[a] and Q ≥ 50.

[b] and Q < 50.

The table shows clearly how the rating scale depends on the value of Q and L and the related BEE index obtained.

3.3 Deutsche Gesellschaft für Nachhaltiges Bauen

The Deutsche Gesellschaft für Nachhaltiges Bauen, referred with the acronym 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. DNGB was lunched in 2009 by the World Green

Building Council, with the aim to promote the building sustainability in Germany and develop the German Certificate for sustainable buildings. DGNB refers to the Environmental Product Declaration developed according to the standards ISO 14025 and EN 15804 and is mostly based on quantitative measures calculated with the Life Cycle Assessment approach.

This evaluation system is flexible and can be applied for national and international environmental assessment, including 13 different building types and, since 2011, entire urban districts.

The system is based on country specific conditions and, the new version 2014, provides the basis for two evaluation routes that vary in scope: International DGNB evaluation route and DGNB localization route. The first consists in the adaptation of the general framework to the local conditions; the second includes a detailed adaptation of the DGNB scheme to the local circumstances within the collaboration with the DGNB Community (local organization and experts). These versions are customized taking into account climate, standards, law, processes and cultural differences. There are active communities, which are currently working on the implementation of the scheme, in Brazil, Chine and Russia [60]. The schemes now available for buildings in Germany are in Table 9.

Table 9 DNGB: Schemes available in Germany.

Building type	**Scheme**
Existing buildings	Offices
	Residential buildings
	Industrial buildings
	Commercial buildings
New buildings	Offices and administration
	Healthcare
	Education facilities
	Hotels
	Retail
	Assembly buildings
	Industrial
	Tenant fit-out
	Industrial locations
New Districts	Urban districts
	Business districts

Regarding the international application, the DGNB provides the Core-14 system that is basically an adaptation of the general framework. It is merely based on the international standards and arises from the DNGB scheme developed for the German context. The worldwide situation about the evaluation is described in Table 10.

Table 10 Worldwide schemes and partners [109] updated on 15/02/2015.

Country	System Partner	Schemes	Registered professionals
Argentina	N/A	International version. Local adaptation in progress	-
Austria	Österreichische Gesellschaft für nachhaltige Immobilienwirtschaft	System adapted.	148
Brazil	DNGB Community - currently working on the adaptation of the international system to Brazilian conditions.	International version. Local adaptation in progress	33
Bulgaria	Bulgarian Green Building Council (BGBC)	System adapted.	4
Chile	N/A	International version. Local adaptation in progress	-
China	DGNB China Community	International version	66
Czech Republic	N/A	International version	1
Denmark	Green Building Council Denmark	System adapted.	205
Greece	N/A	International version	18
Hungary	N/A	International version	2
Italy	N/A	International version	-
Poland	N/A	International version	2
Slovenia	N/A	International version	30
Spain	N/A	International version	12
Switzerland	Schweizer Gesellschaft für nachhaltige Immobilienwirtschaft	System adapted	31
Thailand	ARGE - Archimedes Facility - Management GmbH, Bad Oeynhausen & RE / ECC, Chonburi, Thailand.	System adapted	4
Turkey	N/A	International version	1
Russia	DNGB Community - currently working on the adaptation of the international system to Russian conditions.	International version. Local adaptation in progress	65
Ukraine	N/A	International version	9

The Core-14 for New offices is the only scheme already available in English, while all the others are currently in a process of translation.

The evaluation is based on 63 criteria, subdivided into six categories characterized by a specific weight. The sum of the weights obtained in each category, provides the overall score of the building (Table 11).

Table 11 DNGB: Categories, weights and description.

Categories	Weight	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%	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.

Each criterion can receive a maximum of 10 points. The first four categories have equal weight in the assessment; thus, the DGNB System gives the same importance to the economic aspect and ecological criteria. The are some specific minimum requirements that must be considered as the "Indoor Air Quality" and the "Design for All" included in the Sociocultural and Functional Quality criterion, and the "Legal requirements for Fire Safety and Sound Insulation" included in the Technical Quality criterion. As mentioned, the system is available for urban districts whose minimum size is 2 ha of gross development area where the residential buildings shall not cover less than 10% and not more than 90%. The DGNB schemes for districts include a separate set of criteria, which addresses different issues as express in

Table 12.

Table 12 DNGB: Set of criteria and description for districts.

Subject areas	Criterion	Limit value	Description
Nature conservancy	Biodiversity and networking	10 EP	Overall criterion for ensuring at least the minimum environmental compatibility
Location	Consideration of potential environmental impact	4 EP / 10 EP	Avalanche hazard ("blue zone") Flood risk ("GK3 zone")
Climate protection	Total primary energy requirement and percentage of renewable primary energy	5 EP / 5 EP	Percentage share of renewable primary energy for total primary energy demand.
Social	Social and commercial infrastructure	5 EP / 5 EP	Education. Local services.
Circulation	Quality of the short-distance public transport infrastructure	10 EP	Overall criterion for safeguarding the minimum access to public transport.
Process	Participation	10 EP	Overall criterion for ensuring at least the minimum public participation.

In general, for all the assessment schemes, the score of each performance section is calculated combining the assessment points and the relative weight. For all the schemes the Site quality is evaluated as a separate criterion, except for the case of Urban Districts where it is incorporated in the list of all other general criteria.

It is necessary to achieve a minimum required level in each quality section to obtain the evaluation. The evaluation score is based on nominal performance index and the related DGNB rating scale for the evaluation is presented in Table 13.

Table 13 DNGB: rating scale and performance.

Total performance index, X	Awards
X = 35 %	Certified
35 < X ≤ 50 %	Bronze
50 < X ≤ 65 %	Silver
65 < X ≤ 80 %	Gold

3.4 Haute Qualité Environnementale

The *Haute Qualité Environnementale* standard, referred with its acronym HQE™, was developed in 1994 in France by the HQE™ Association. This association supports stakeholders, designers, partners, developers and users during the projects phases, aiming to guarantee a high environmental quality of buildings. The HQE™ Association has developed a large number of schemes, exploitable both in France and outside France. There are three bodies in charge of delivery evaluation in France and one for supporting the evaluation across the world [98].

HQE™ covers buildings throughout their life cycle, such as design, construction, operation and renovation. It is addressed to non-residential, residential buildings and detached houses. Furthermore, a specific scheme for the management system of the urban planning and development projects is also available. The HQE™ evaluation implements a multi-criteria decision making approach and requires that a qualified professional called the "Référent" assists the assessment process.

HQE™ is an environmental assessment system, which is made of several assessment schemes. They are organized in one international scheme and in three systems dedicated to France and addressed to (i) non-residential buildings, (ii) residential buildings and (iii) detached houses. Each French system is managed by a specific organization. The schemes make reference to a common framework but, in several cases, they diverge in a few significant parts. This topic is worth deserving a detailed analysis, but this goes beyond the purpose of this thesis and will be omitted.

The Project Management System (PMS) scheme has a completely different structure and has been developed to assess urban planning and development projects. It sets out the requirements for each phase of the project dividing them into specifics and recurring cyclic requirements. The structure of the PMS consist of six phases [111], listed in

Table 17 together with the specific requirements.

Table 17 reports the organization in charge and the specific scheme that they manage.

Table 14 HQE™: Certivèa assessment schemes.

Name of the managing organization	**Territorial competence**	**Scope of the system**	**Purpose or building phase**	**Name of the schemes**
Certivèa	France	Non residential buildings Urban planning	New constructions Renovations	Bâtiments Tertiaires - Neuf ou Rénovation
				Equipements Sportifs - Neuf ou Rénovation
			Operation phase	Bâtiments Tertiaires en Exploitation
			Urban planning	Project Management System
Cerqual	France	Residentiual building	New construction	NF Logement
				NF Logement HQE™
				Qualité et Habitat & Environnement
			Renovations	Patrimoine Habitat (& environnement)
				Patrimoine Copropriété (& environnement)
				NF Maison Rénovée
Cèquami	France	Detached house	New construction	NF Maison Individuelle
				NF Maison Individuelle HQE™
			Renovations	NF Maison Rénovée démarche par chantier
				NF Maison Rénovée HQE™
				NF Maison Rénovée
Cerway	International	Residential buildings Commercial buildings Administrative builindgs Buildings for public services	New constructions Renovations Operation phase	HQE™™ for Building under Construction
				HQE™™ for Building in Operation.
				HQE™™ for Urban Planning and Development

The Certivèa body deals with the assessment of local planning and non-residential buildings that are being built, renovated or used in France. The Cerqual body is in charge of the assessment of residential, renovated or used buildings in France. The Cequami deals with the evaluation of detached houses in France. The last body in charge to assess the environmental sustainability is the Cerway. It manages the projects out of France for the full duration of their design.

The building type that can be taken into account by the Cerway are: residential, commercial, administrative or for services under construction, in operation and under renovation. The only exception regards the Principality of Monaco, where the evaluation may be request and delivered to Certivea [110]. Both the International and the French protocols are based on the same framework and the Cerway's schemes are adaptation from Certivéa's ones.

Table 15 HQE™: 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			

The environmental performance requirements are basically organized into four topics descripted by 14 targets. Topics are quite the same for all buildings types instead the targets are arranged differently for residential buildings or non-residential buildings .

Table 16 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	

A building project can obtain an assessment in each target expressed according to three ordinal levels: “Basic”, “Performing” and “High Performing”. To get the evaluation the building must achieve the “High Performing” level in at least three categories and the “Basic” level in a maximum of seven categories. This rating scheme does not weight each target by a weighting factor, because they are considering having the same importance within the assessment framework.

The schemes make reference to a common framework but, in several cases, they diverge in a few significant parts. This topic is worth deserving a detailed analysis, but this goes beyond the purpose of this thesis and will be omitted.

The Project Management System (PMS) scheme has a completely different structure and has been developed to assess urban planning and development projects. It sets out the requirements for each phase of the project dividing them into specifics and recurring cyclic requirements. The structure of the PMS consist of six phases [111], listed in

Table 17 together with the specific requirements.

Table 17 HQE™: phases and specific requirements for the Project Management System.

Phases	Specific requirements
Phase 1: Launch	Expectations and motivation of the local government(s)
	Developer involvement in the HQE™ for Urban Planning and Development initiative
	Involvement of the local government(s) in the HQE™ for Urban Planning and Development initiative
	Management methods for the project
	Participation of the stakeholders
	Multi-disciplinary team
Phase 2: Initial analysis	Diagnostic for sustainable development
	Overview of regulations and regional initiatives
	Sharing the diagnostic
	Suitability of the project for sustainable development
Phase 3: Selection of objectives	Thematic analysis of the initial studies
	Prioritizing the challenges
	Separating the challenges into objectives
	Awareness of the parties involved
	Objectives charter
Phase 4: Sustainable project design	Project program
	Sustainable project scheme and layout
	Design incorporating sustainable development

Phases	Specific requirements
Phase 5: Implementation	Transforming sustainable development objectives into requirements Verification and monitoring during the execution Assessment of construction projects Worksite management Buyer and future user awareness Buyer and manager information
Phase 6: Overall assessment	Project overall assessment HQE™ for Urban Planning and Development initiative overall assessment Capitalization

The evaluation rating performance scale is expressed in number of stars and the global performance level reached by the buildings is calculated on the basis of total number of stars obtained in each issue (Table 18).

However, regardless of the number of stars earned, the achievement of all the prerequisites is necessary to reach the evaluation. Moreover, to reach the Exceptional Level, 3 stars must be earned in the energy theme.

Table 18 HQE™: Rating scale and minimum levels to achieve.

Assessment Level	Scoring scale (stars)
HQE™ Exceptional	$X \geq 12^c$
HQE™ Excellent	$9 \leq X \leq 11$
HQE™ Very Good	$5 \leq X \leq 8$
HQE™ Good	$1 \leq X \leq 4$
HQE™ Pass	0^d

3.5 Leadership in Energy and Environmental Design

The first Leadership in Energy and Environmental Design Pilot Project Program, referred to as LEED® Version 1.0, was launched in U.S.A. in 1998 by the US Green Building Council of US Department of Energy (USGB), a non-governmental organization which includes representatives from industry, academia and government [112]. From that time, the

LEED® system has undergone to some revisions, integrations and national customizations.

The LEED® Version 3.0 has been released in 2009 and it is currently in use, except for the specific scheme entitled *LEED® for Home multi-family midrise*, whose latest version was launched in 2010.

The American LEED® Version 3.0 consists of several specific systems suitable to the different structural arrangements. Each system contains an array of schemes that recognizes specific project requirements. The American LEED® has been adapted to foreigner national contests. Specifically, the Canadian and Indian Green Building Councils have created their own tailored version of LEED®, while Green Building Councils or research groups of Argentina, Brazil, Italy and of dozen other countries are developing or using adaptations of the American framework [54].

Available rating systems have been proposed to deal with (i) different building sectors, (ii) specific building typologies, (iii), building operational and maintenance and (iv) project scopes. The American LEED® Version 3.0 family of system is reported in Table 19.

Table 19 The American LEED® Version 3.0 rating systems per project type and description.

Rating system	**Project type**	**Description**
Building design + Construction	New Construction Core & Shell Schools Retail Hospitality Data Centers Warehouses & Distribution Centers Healthcare	Applied to buildings that are being newly constructed or going through a major renovation.
Interior design + Construction	Commercial Interiors Retail Hospitality	Applies to projects that are a complete interior fit-out.
Building operations + Maintenance	Existing Buildings Schools Retail Hospitality Data Centers Warehouses& Distribution Centers	Applies to existing buildings that are undergoing improvement work or little to no construction
Neighborhood development	Plan Built Project	Applies to new land development projects or redevelopment projects containing residential uses, non-residential uses, or a mix. Projects can be at any stage of the development process, from conceptual planning to construction.

Rating system	Project type	Description
Homes	Homes and Multifamily Low-rise Multifamily Midrise	Applies to single-family homes, low-rise multi-family (one to three stories), or mid-rise multi-family (four to six stories).

The use of the LEED® Green Building Rating Systems is voluntary. Each system aim at assessing the environmental performance of the whole building over its life cycle. These systems are designed for rating new and existing commercial, institutional and residential buildings. Each rating system is a list of performance requirements set in five categories with 100 points, plus additional two categories that give the opportunity for up to 10 bonus points. Table 20 provide a description of the categories included in the LEED® environmental assessment tool.

The LEED® Green Building Rating Systems are voluntary and evaluate the environmental performance of the whole building over its life cycle. These systems are designed for rating new and existing commercial, institutional and residential buildings. Each rating system is a list of performance requirements set in five categories with 100 points, plus additional two categories that give the opportunity for up to 10 bonus points. Table 20 provide a description of the categories included in the LEED® environmental assessment tool.

Table 20 LEED®: categories and description

Categories	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 subject 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 is promoted the building energy performance improvement, the use of renewable sources and the energy building performance control.
Materials and resources	In this area are considered the environmental subjects associated to the materials selection, the reduction of virgin material use, the garbage disposal and the environmental impact due to transport.
Indoor environmental quality	The themes taken into account in this section cover the indoor environmental quality as healthiness, comfort, energy consumption, air renewal and the air pollution control.
Innovation in design	The aim of this section is 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.

The LEED® 2009 uses the U.S. Environmental Protection Agency's TRACI environmental categories as basis for weighting the credits [96]. Their allocation is based on the potential environmental impacts and the human benefits of each credit with respect to a set of impact categories. All the credits receive a single weight in each rating system. The base points totally available are 100, including 40 points that have to be obtained for the basic evaluation. To provide incentives for local specific environmental issues, USGBC identified six credits per rating system that are of particular importance to specific areas. Each regional priority credit is worth for getting an additional point, and a total of four regional priority points may be earned.

Each scheme presents the same list of criteria, but the number of credits, prerequisites and available points change considerably according to the specific area of interest and the building type. Almost all schemes present mandatory prerequisites and non-compulsory credits, which can be selected according to the objectives to achieve. The summation of points for each credit generates the evaluation outcome.

Table 21 LEED®: rating score and related points.

Assessment Level	**Scoring Scale (points)**
Platinum	$X \geq 80$
Gold	$60 \leq X \leq 79$
Silver	$50 \leq X \leq 59$
Certified	$40 \leq X \leq 49$

3.6 SB Method

In 1996, the international Green Building Challenge initiative, which was later named Sustainable Building Challenge (SBC), set the goal to establish the energy and environmental performance standards, suitable both in the international and national context. It was therefore necessary to identify the assessment tools that, through different methodological bases, were able to objectively assess the requirements of the environmental, economic and social structures of a building during its whole life cycle. This process led to a method, originally called SBMethod and later re-named SBTool, aimed at the quantification by assigning scores and credits. Developed by the work of representatives from 20 countries, the SBTool is a generic framework for rating the performance of buildings and projects. It can be used by authorized third parties to establish adapted versions, through the introduction of meaningful benchmarks, as rating systems to suit regional requirements and building types. The national rating schemes currently available are:

- *Protocollo ITACA* (Italy): launched in 2012 and managed by ITACA (the Italian Conference of Regions and Autonomous Provinces) with the scientific support of iiSBE Italia and ITC-CNR, member of the SBA;
- SBToolCZ (Czech Republic): launched in 2010 and developed by the iiSBE in collaboration with the CIDEAS research center at the Faculty of Engineering of the Czech Technical University in Prague. Two evaluation bodies carry out the operation of the SBToolCZ evaluation scheme: the TZÚS Praha (the Prague Technical and Test Institute for Construction – a member of the SBA) and VÚPS – Certifikační společnost (Research Institute for Buildings – Evaluation Body);
- SBToolPT (Portugal): developed by iiSBE Portugal in collaboration with the LFTC-UM (the Building Physics and Construction Technologies Laboratory at the Civil Engineering Department of the University of Minho) and ECOCHOICE. The two resulting national evaluation schemes are the SBToolpt-H for housing and the SBToolpt-SPTU for Tourism, Commercial and Urban Planning Projects development in-progress;
- Verde (Spain): adopted by the Green Building Council España (GBCe). The GBCe trains and appoints the Verde's authorized assessors, reviews the Verde's assessments and delivers certificates. Its technical committee is also responsible for the on-going development of the scheme.

The method is structured in a way that to each parameter is settled with a weight. This procedure is used to calculate with the right importance the parameters involved but, in any case, the total sum must add to 100 %. The parameters are calibrated for different building types, such as single buildings, residential or commercial, new and existing constructions, or a mix of the two. The system provides separate modules for Site and Building assessments, carried out in the Pre-design phase, and Building assessments in Design, Construction or Operation phases [96]. The performance framework of the SBTool is organized in four levels, namely: (i) performance issue, (ii) performance categories, (iii) performance criteria and (iv) performance sub-criteria.

The performance issue potentially active, the scopes and the phases for the assessment, are listed in Table 22

Table 22 SBTool: generic and active criteria by Issue and Phase [113].

Issue area	Scope	Pre-design	Design	Construction	Operation
Site location, available services and site characteristics	Max	35			
	Mid	20			
	Min	8			
Site regeneration and development. Urban design and infrastructure	Max		22	0	21
	Mid		12	0	11
	Min		2	0	2
Energy and resource consumption	Max		10	6	10
	Mid		8	4	7
	Min		4	2	3
Environmental loadings	Max		19	7	18
	Mid		6	1	6
	Min		2	0	2
Indoor environmental quality	Max		18	0	19
	Mid		10	0	10
	Min		2	0	2
Service quality	Max		20	9	25
	Mid		10	4	13
	Min		2	1	2
Social, cultural and perceptual aspects	Max		10	2	10
	Mid		5	1	5
	Min		1	0	1
Cost and economic aspects	Max		4	1	4
	Mid		3	1	3
	Min		1	0	1
Total system	Max		103	25	107
	Mid		54	11	55
	Min		14	3	13

The performance issue contains the categories that represent the field in a more detailed and characteristic way. The last two levels of the assessment are represented by the criteria and sub-criteria that indicate the prominent feature of the building performance. In In 1996, the international Green Building Challenge initiative, which was later named Sustainable Building Challenge (SBC), set the goal to establish the energy and environmental performance standards, suitable both in the international and national context. It was therefore necessary to identify the assessment tools that, through different methodological bases, were able to objectively assess the requirements of the environmental, economic and social structures of a building during its whole life cycle. This process led to a method, originally called SBMethod and later re-named SBTool, aimed at the quantification by assigning scores and credits. Developed by the work of representatives from 20 countries, the SBTool is a generic framework for rating the performance of buildings and projects. It can be used by authorized third parties to establish adapted versions, through the introduction of meaningful benchmarks, as rating systems to suit regional requirements and building types. The national rating schemes currently available are:

- *Protocollo ITACA* (Italy): launched in 2012 and managed by ITACA (the Italian Conference of Regions and Autonomous Provinces) with the scientific support of iiSBE Italia and ITC-CNR, member of the SBA;
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The performance issue potentially active, the scopes and the phases for the assessment, are listed in Table 22

Table 22, each issue is associated to a score that changes in relation to the assessed phase and the scope. The user can select one of the four scope options (also the Developer scope, not represented in the table due to lack of sources), which determines the number of active generic criteria. All users must review, modify or replace these for producing a locally relevant version. In some cases the criteria can be turned off for reducing the number of the issues taken into account, with the exception of a small number of mandatory criteria. The meaning of the "Scope" item showed in the table is:

- Maximum scope: this version contains all criteria fully developed with benchmarks;
- Mid-size scope: this version covers the most important performance issues;
- Minimum scope: this version contains the minimum number of criteria to cover key issues.

Regarding the different assessment phases, SBTool provides a separate sheet for the Pre-Design which not includes information about the following project development. Moreover, the Operation phase, focused on the operating performance, is assessed not earlier than two years of occupancy.

As an example, the list of all the specific criteria included in the Minimum scope version for the Design Phase are shown here below [99]. All the underlined criteria are mandatory:

- Impact of orientation on the passive solar potential of building(s);
- Provision of on-site parking facilities for private vehicles;
- Embodied non-renewable energy in original construction materials;
- Consumption of non-renewable energy for all building operations;
- Degree of re-use of suitable existing structure(s) where available;
- Use of water for occupant needs during operations;
- GHG emissions from primary energy used for all purposes in facility operations;
- Impact on access to daylight or solar energy potential of adjacent property;
- Carbon-dioxide concentrations in indoor air;
- Appropriate day lighting in primary occupancy areas;
- Occupant egress from tall buildings under emergency conditions;
- Adaptability to future changes in type of energy supply;
- Access for mobility-impaired persons on site and within the building;
- Affordability of residential rental or cost levels.

The scoring in the SBTool is based on a series of comparisons between the characteristics of building and national, or even local, minimum standards. In the weighted summation, the score is calculated first by multiplying each value by its appropriate weighting factor and then totaling the scores for all criteria. The scoring scale is provided in In 1996, the international Green Building Challenge initiative, which was later named Sustainable Building Challenge (SBC), set the goal to establish the energy and environmental performance standards, suitable both in the international and national context. It was therefore necessary to identify the assessment tools that, through different methodological bases, were able to objectively assess the requirements of the environmental, economic and social structures of a building during its whole life cycle. This process led to a method, originally called SBMethod and later re-named SBTool, aimed at the quantification by assigning scores and credits. Developed by the work of representatives from 20 countries, the SBTool is a generic framework for rating the performance of buildings and projects. It can be used by authorized third parties to establish adapted versions, through the introduction of meaningful benchmarks, as rating systems to suit regional requirements and building types. The national rating schemes currently available are:

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The performance issue potentially active, the scopes and the phases for the assessment, are listed in Table 22

Table 22.

Table 23 SBTool: scoring scale and assessment level.

Scoring Scale	Assessment Level
-1	Deficient
0	Minimum acceptable performance
3	Good practice
5	Best practice

3.7 National systems

The globalization, combined with the increasing attention on the environment, has driven to a great interest for environmental assessment systems for buildings. Since their origin in 1990, the growing request for the environmental assessment tools has led to the development of a wide number of national schemes. The past decade has witnessed many countries worldwide to make efforts to implement the schemes, in order to make them more flexible and adaptable to local contexts. This carried to adjust the schemes in order to suit their specific climatic and cultural contexts. In this section, a few national customizations of international schemes is proposed.

The BREEAM system, originally developed for United Kingdom, has been adapted for: Austria (BREEAM-AT), Germany (BREEAM-DE), Luxembourg (BREEAM-LU), Netherlands (BREEAM-NL), Spain (BREEAM-ES), Sweden (BREEAM-SE), and Switzerland (BREEAM-CH).

The DGNB system, originally developed for Germany, has been adapted for: Austria, Bulgaria, Denmark, Switzerland, and Thailand. The adaptation is still on going for: Argentina, Brazil, Chile, and Russia. Meanwhile, the countries which are currently using the international version are: Argentina, Brazil, Chile, China, Czech Republic, Greece, Hungary, Italy, Poland, Spain, Turkey, Russia, and Ukraine.

The Green Globes system, originally developed for Canada, has been adapted for the United States by the Green Building Initiative.

The Green Star system, originally developed for Australia, has been adapted for the South Africa by the South Africa Green Building Council.

The HQE™ Method, originally developed for France, has been adapted by the Fundação Vanzolini for Brazil.

The LEED® system, originally developed for the United States, has been adapted by for: India, Italia, Canada, Argentina, and Brazil.

The generic framework SBTool, has been adapted by iiSBE for: Italy (Protocollo ITACA), Portugal (SBTool PT), Spain (Verde), and Czech Republic (SBTool CZ).

Conclusions

This chapter focuses on the presentation of the six selected systems: BREEAM, CASBEE, DGNB, HQE™, LEED® and SBTool. The structure and the technical characteristics of each system have been described in detail. Moreover, an overview of the main available customizations is proposed. Based on the data acquired, the following conclusions can be stated:

- Despite the large-scale development of schemes and the proliferation of customizations, it must be pointed out that an increased flexibility of the methods does not imply necessarily a better assessment of the sustainability of a building.
- The systems with the largest number of customizations are DGNB, LEED® and BREEAM. However, it can be noticed that BREEAM has been adapted only by European countries, while customizations of LEED® can be found worldwide. On the other hand, in many cases, it could just be the result of a better marketing strategy.

Chapter 4

Analysis of selected multi-criteria decision making methods

This chapter is focused on the analysis and comparison of the six schemes that have been selected in the Chapter 3 and that will be reported here for sake of completeness: Building Research Establishment Environmental Assessment Methodology (BREEAM), Comprehensive Assessment System for Built Environment Efficiency (CASBEE), Deutsche *Gesellschaft für Nachhaltiges Bauen* (DGNB), *Haute Qualité Environnementale* (HQE™), Leadership in Energy and Environmental Design (LEED®) and SBTool. The used methodology is introduced first, specifying the original sources of the data that are reported and explaining the rationale behind the proposed study.

The analysis is carried out based on a series of tables, each one emphasizing a particular aspect of the schemes to be compared in order to highlight how this influences the applicability and the efficiency of the methods. The considered items are: *project type, building type, life cycle phase of the building, rating score and scopes*. Project type refers to the nature of the intervention, in particular if it applies whether to a new or an existing building, or if it concerns a refurbishment. In the building type category a distinction is made on the basis of the determined residential, commercial or industrial use. The life cycle of a building comprehends several phases, such as design, construction, use and maintenance. The rating score analysis is focused on the comparative study of the percentage weights that define the score system of each scheme, as well as on the classification of mandatory and optional criteria.

The table proposed at the end of the chapter shows the schemes available within each, highlighting the categories that have been organized in scopes. The arrangement of such scopes has been pursued taking into account all the aspects involved in the environmental performance evaluation with the aim of simplifying the comparison between the schemes.

4.1 Methodology

The scope of the following analysis is to compare the assessment schemes on the basis of several tables in which the data are grouped according to the selected categories to be investigated.

The great majority of the data used in this study has been acquired directly from official technical manuals of the assessment schemes. Additional material has been collected from the official homepages of the schemes or from past scientific reviews in this field. However, the literature concerning the schemes, their structure and content, is rather limited and most of the proposed reviews only pertain applications of the schemes to local case studies.

In this regard, we point out that the building environmental assessment schemes included in this analysis are considered at an international level when dealing with general comparison, while referring to the comparison of scopes the details of each particular scheme included in the systems have been exploited. On the other hand, the schemes have not been tested for the study, which is exclusively based on elaboration and evaluation of the officially declared attributes of the schemes.

Although the aim of this work is to attempt to give an exhaustive comparison of the available frameworks, we have been forced to limit the number of schemes included in the study to reduce complexity and guarantee a sufficient readability of the results. We notice also that the systematic comparison of the schemes is difficult, sometimes prohibitive. As a matter of fact, different assessment schemes have been developed for different purposes and hence a precise correspondence of categories and sub-categories is often not achievable.

4.2 Overall comparison of the schemes

As already mentioned, the number of environmental assessment schemes is broad and the goal of this section is to give insights into the subject by the analysis and comparison of a selection of existing schemes. Exploiting the schemes categories, similarities and differences can be evinced. In this section the system are characterized according to the categories:

- Project type;
- Assessed buildings;
- Phase of life cycle;
- Rating score;
- Scopes.

Building environmental assessment schemes can be used to assess existing buildings, new buildings and buildings under refurbishment. Each one of selected schemes for this study can be applied to the three project types just mentioned, except for SBTool, which does not assess performances of refurbishments.

Assessment schemes can be used to certify the environmental performances of different type of buildings:

- Residential;
- Office;
- Commercial;
- Industrial;
- Educational;

All the buildings that do not fit any of the above categories are grouped in the field named *Other type of buildings*. Moreover, in certain cases, dedicated schemes exist also for *Urban planning*.

Table 24 Building type assessed by the selected schemes

Assessment tool	**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

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- Commercial;
- Industrial;
- Educational;

All the buildings that do not fit any of the above categories are grouped in the field named *Other type of buildings*. Moreover, in certain cases, dedicated schemes exist also for *Urban planning*.

Table 24, BREEAM, CASBEE, DGNB and HQE™ schemes evaluate all the admissible building types. On the other hand, the building types belonging to the categories *Residential, Office, Commercial* and *Educational* are assessed by all the schemes. It can be noticed that both LEED® and SBTool do not include in the evaluation the *Industrial buildings* type; moreover, the latter scheme does not consider *Urban planning* either.

The life cycle of a building, according to the "cradle-to-grave" principle, is divided into several phases. In this study the considered phases are:

- Pre-design and design;
- Construction;
- Post-construction;
- Use and maintenance.

Table 25 Life cycle phase of the building assessed by the selected schemes

Assessment tool	**Pre-design phase and Design phase**	**Construction**	**Post-construction**	**Use/ Maintenance**
BREEAM	•	•	•	•
CASBEE	•	•	•	•
DGNB	•	•	•	•
HQE™	•	N/A	•	•
LEED®	N/A	•	•	•
SBTool	•	•	•	N/A

Referring to Table 25, it can be noticed that BREEAM, CASBEE and DGNB schemes assess all the four considered life cycle phases of buildings and that, conversely, the only phase to be evaluated by every scheme is "Post-construction". In this regard, we can see that: HQE™ does not assess "Construction" phase; LEED® does not evaluate "Pre-design/Design"; SBTool does not estimate performances for "Use/Maintenance" phase.

The results of the environmental assessment of a building can be presented in forms of graphs, tables, grades, certificates and reports [14]. Tables are the most common output form of results, but for some schemes, such as CASBEE, graphs are also a fundamental component of the presentation of the ranking.

Table 26 displays the rating scale that each system uses to express their output. All the environmental systems associate a numerical value to each reachable target, in order to make the results more clear and quantifiable. In particular, BREEAM and DGNB provide a percentage range associated with the targets, while HQE™ and LEED® attribute stars and points respectively. The SBTool ranking scale has a range from -1 to 5; it is interesting to notice that this is the only assessment scheme, within the ones selected for the study, to associate a value less than zero to the performance.

Table 26 Rating scale for the assessment schemes

CASBEE		BREEAM		HQE		SBTool		DGNB		LEED	
Assessment level	**Scoring Scale (BEE)**	**Assessment level**	**Scoring Scale (%)**	**Assessment level**	**Scoring Scale (stars)**	**Assessment Level**	**Scoring Scale (points)**	**Assessment level**	**Scoring Scale (%)**	**Assessment level**	**Scoring Scale (points)**
-	-	-	-	Exceptional	$X \geq 12$[c]	-	-	-	-	-	-
Excellent	$X > 3.0$[a]	Outstanding	$X \geq 85$	Excellent	$9 \leq X \leq 11$	-	-	Gold	$65 < X \leq 80$	Platinum	$X \geq 80$
Very good	$1.5 \leq X < 3.0$ *OR* $X > 3.0$[b]	Excellent	$70 \leq X < 85$	Very good	$5 \leq X \leq 8$	Best practice	5	Silver	$50 < X \leq 65$	Gold	$60 \leq X \leq 79$
Good	$1.0 \leq X < 1.5$	Very good	$55 \leq X < 70$	Good	$1 \leq X \leq 4$	Good practice	3	Bronze	$35 < X \leq 5$	Silver	$50 \leq X \leq 59$
Fairy poor	$0.5 \leq X < 1.0$	Pass	$30 \leq X < 55$	Pass	0[d]	Min acceptable performance	0	Certified	$X = 35$	Certified	$40 \leq X \leq 49$
Poor	$X < 0.5$	Unclassified	$X < 30$	-	-	Deficient	-1	-	-	-	-

[a] and $Q \geq 50$.

[b] and $Q < 50$.

[c] with at least 3 stars for the energy theme.

[d] but all pre-requirements have been succesfully met.

Due to the wide variety of subcategories and the heterogeneity of the nomenclature within each single system, some of the categories have been re-arranged to minimize to make them comparable. As a matter of fact, referring to 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.

Table 27: Scopes

Assessment scheme	**Scopes**																											
	Energy					**Indoor environmental quality**					**Innovation**	**Management**			**Materials and resources**				**Pollution and waste**				**Resistance against natural disasters**		**Site quality**			
	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	Materials reuse	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 2015	•		•	•			•	•	•	•		•	•			•	•	•	•	•	•	•			•	•		•
BREEAM UK New Construction 2014	•			•	•		•	•	•	•	•	•				•	•	•	•	•	•	•			•	•		•
BREEAM UK Domestic Refurbishment 2014	•	•	•	•			•		•		•	•	•			•	•				•	•						•
BREEAM UK Non-Domestic Refurbishment & Fit-Out 2014	•			•	•		•	•	•	•	•	•				•	•	•	•	•	•	•			•	•		•

Assessment scheme	Scopes: **Energy**					**Indoor environmental quality**					**Innovation**	**Management**			**Materials and resources**				**Pollution and waste**				**Resistance against natural disasters**		**Site quality**			
	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	Materials reuse	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 UK Datacentres 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 Retails) 2014	•	•			•		•	•							•		•	•				•	•			•		•
CASBEE for Urban Development 2014	•				•							•		•	•	•	•	•			•	•	•		•	•	•	•
CASBEE for Cities 2012														•			•	•				•			•		•	•
	DGNB																											
DGNB Core 14	•	•	•	•			•	•	•	•		•	•	•	•		•	•	•		•	•	•	•	•	•	•	•

Assessment scheme	Scopes: Energy					Indoor environmental quality					Innovation	Management			Materials and resources				Pollution and waste				Resistance against natural disasters		Site quality			
	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	Materials reuse	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
HQE™																												
NF Maison Individuelle Neuf 2013	•	•	•			•	•	•	•	•		•				•	•	•	•	•		•		•		•	•	•
NF Maison Rénovée 2014	•	•	•	•		•		•	•							•	•		•		•	•		•			•	•
NF Logement Habitat Neuf	•		•	•	•	•	•	•	•	•						•	•		•			•					•	•
NF Qualité Environnementale des Bâtiments 2015	•				•	•	•	•	•	•					•		•		•			•					•	•
NF Bâtiment Durable 2014	•					•	•	•	•	•						•	•								•	•	•	•
HQE™ Buildings in Operation Sustainable Management 2014	•		•	•	•	•	•	•	•	•						•	•				•	•						•
HQE™ Infrastructures				•	•				•			•		•		•	•	•	•						•	•		•
Habitat & Environnement	•			•			•	•	•	•		•	•	•	•	•	•					•				•	•	
HQE™ Management System for Urban Planning Projects 2014	•	•	•	•	•	•	•	•	•	•		•		•		•	•	•	•		•	•			•	•	•	•

Assessment scheme	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	Materials reuse	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
	Scopes																											
	Energy					**Indoor environmental quality**					**Innovation**	**Management**			**Materials and resources**				**Pollution and waste**				**Resistance against natural disasters**		**Site quality**			
	LEED®																											
LEED® for Homes Rating System Multifamily Mid-Rise 2010	•		•		•					•		•	•				•	•				•			•	•		•
LEED® for Existing Buildings Operation and Maintenance 2009	•	•	•	•			•	•	•	•	•	•				•	•			•		•				•		
LEED® for Retail: New Construction and Major Renovations 2009	•	•	•	•			•	•		•	•				•	•	•			•	•	•			•			
LEED® for Commercial Interiors 2009	•	•	•	•			•	•		•	•				•	•	•			•					•	•		
LEED® for Retail: Commercial Interiors 2009	•	•	•	•				•		•	•				•	•	•			•	•	•			•	•		•
LEED® for Schools New Construction and Major Renovations 2009	•	•	•				•	•	•	•	•				•	•	•			•	•	•			•	•		•
LEED® for Healthcare 2000	•	•	•	•			•	•	•	•	•					•	•			•		•				•	•	•

Assessment scheme	Scopes																											
	Energy					**Indoor environmental quality**					**Innovation**	**Management**			**Materials and resources**				**Pollution and waste**				**Resistance against natural disasters**		**Site quality**			
	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	Materials reuse	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® for Core and Shell Development 2009	•	•	•	•			•	•		•	•				•	•	•	•		•	•	•						
LEED® for Neighborhood Development 2009	•	•									•				•		•	•		•	•	•			•	•	•	•
	SBTool																											
SBTool assessment framework 2012	•			•	•		•	•	•	•				•		•	•		•		•	•			•	•	•	•

Starting from an array of 33 schemes, selected on the basis of their accessibility on the official websites and sometimes by direct contact with the promoting associations, a qualitative and quantitative comparison has been performed. In Due to the wide variety of subcategories and the heterogeneity of the nomenclature within each single system, some of the categories have been re-arranged to minimize to make them comparable. As a matter of fact, referring to 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.

Table 27, we can see that, based on an overall analysis of the scopes, the most accounted are *Energy performance* and *Water*. Such completeness is motivated by the fact that such categories constitute fundamental issues related to the performance evaluation of a building or a urban district. Other important categories are *Solid waste management, Visual comfort, Thermal comfort, Materials* and *Ecology and environmental quality,* which are assessed by the great majority of schemes. It can be easily noticed that the scopes less accounted for are those related to *Resistance to natural disasters*, which are considered only by CASBEE for Homes and Detached House, DGNB Core 14, HQE™ Maison Individuelle Neuf and Rénovée. Similarly, the category *Olfactory comfort* is specifically assessed only by the schemes in HQE™, while in the other systems is included in the more general category *Air quality.* Finally, *Building Information and users guide* is considered only by the schemes of the BREEAM system, and in some isolated cases by schemes in LEED®, HQE™ and DGNB. In Figure 14, to support the results, the scopes distribution among the scemes is presented graphically.

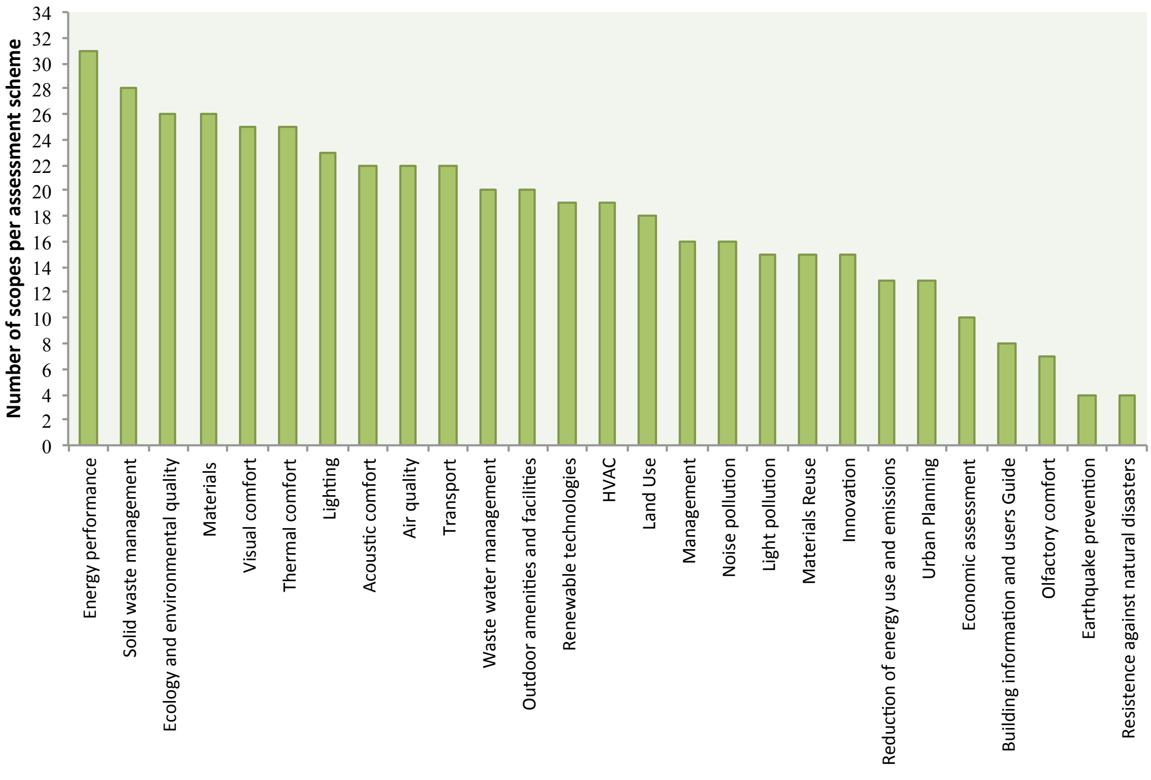


Figure 14 Scope distribution among the schemes.

Performing a complete and transversal comparison of all schems is practically unfeasible and hence, for the sake of simplicity, the most complete schemes within each system have been identified and compared. Regarding BREEAM, the scheme that takes into account the largest number of categories is BREEAM UK Datacentres 2010, with 23 categories out of 28. Within the CASBEE schemes, both CASBEE for Home (Detached Houses) 2007 and CASBEE for Building (New Construction) 2014 assess 23 categories. The most complete HQE™ scheme is HQE™ Management Systam for Urban Planning Projects 2014, while within the LEED® system we can find LEED® for Schools New Construction and Major Renovations 2009. Both DGNB and SBTool have made available a single scheme, respectively DGNB Core 14 and SBTool framework 2012.

It follows from the analysis that a direct relationship between categories and scheme purpose does not exist. In particular, the most complete schemes of each system do not belong to the same class. In general, the most limited systems are those referring to urban district, namely BREEAM Communities 2012, CASBEE for Cities 2012, HQE™ Infrastructures, and LEED® for Neighborhood Development 2009, which as for clear reasons disregard the scope *Indoor environmental quality*. Moreover within the LEED® system, the scheme LEED® for Homes Rating System Multifamily Mid-Rise 2010, which refer to a very specific building target, is quiet delimited.

A quantitative comparison is achievable if restricted to groups of schemes with a common purpose. Five groups have been selected: Commercial, Refurbishment, In-Use, New Construction and Urban Planning. The number of categories assessed in each scheme is represented in Figure 15: we point out that the only schemes taken into account are those striclty specific to the relative group. In particular, the zero level of a system in some of the graphs means that the system does not include any specific scheme for the considered field, even though it may assess the same domain within a more general or transversal scheme. The particular schemes accounted for in Figure 15 are listed below, while the remaining ones have not taken into consideration due to lack of comparison causes:

1. New Construction
    a. BREEAM UK New Construction 2014
    b. CASBEE for Building New Construction 2014
2. Commercial
    a. BREEAM Europe Commercial 2009
    b. CASBEE for Market Promotion: Office and Retails 2014
    c. LEED® for Retail: New Construction and Major Renovations 2009
    d. LEED® for Commercial Interiors 2009
    e. LEED® for Retail: Commercial Interiors 2009
3. In Use

a. BREEAM In-Use International 2015

b. HQE™ Buildings in Operation Sustainable Management 2014

c. LEED® for Existing Buildings Operation and Maintenace 2009

4. Refurbishment

a. BREEAM UK Domestic Refurbishment 2014

b. BREEAM UK Non-Domestic Refurbishment & Fit – Out

c. HQE™ NF Maison Rénovée 2014

5. Urban Planning

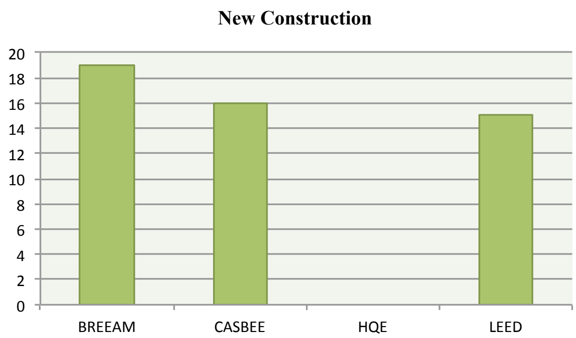
a. BREEAM Communities 2012

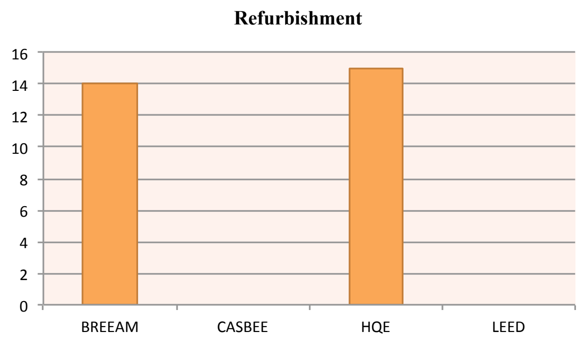
b. CASBEE for Urban Development 2014

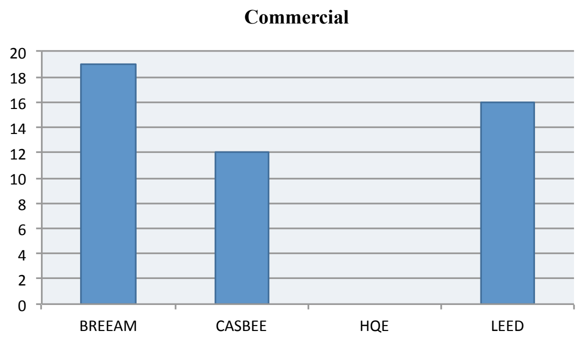
c. CASBEE for Cities 2012

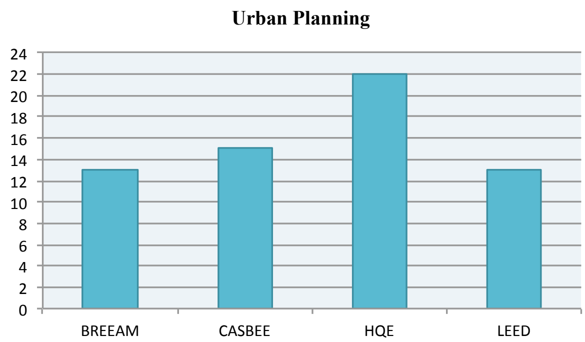
d. HQE™ Management System for Urban Planning Projects 2014

e. LEED® for Neighborhoos Development 2009









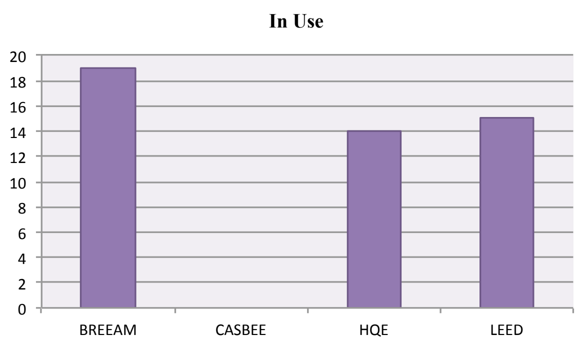


Figure 15 Comparison among restricted groups of schemes.

Conclusions

In this chapter the six systems selected in Chapter 3 have been analyzed. Through a series of tables, the analysis has been performed by considering the following items: *project type*, *building type*, *life cycle phase of the building*, *rating score and scopes*. Based on the evaluation of data and interpolating the results discussed previously, the following conclusions can be stated:

- In the *project type* item, all the schemes are suitable for new and existing buildings; every scheme except SBTool is suitable also for the refurbishment of buildings;
- All the categories fitting in the *building type* field are assessed by BREEAM, CASBEE, DGNB and HQE™;
- All the categories fitting in the *life cycle phase of the building* field are assessed by BREEAM, CASBEE and DGNB;
- BREEAM, CASBEE and DGNB seem to be the most complete frameworks, since these assess the widest range of items within the aforementioned fields;
- SBTool is the unique system to have been designed for certifying also a low performance level of the buildings;
- The only category that is assessed by all schemes is *Water*, directly followed by *Energy performance*. These are two fundamental elements of the environmental performance evaluation of a building;
- *Solid waste management, Visual comfort, Thermal comfort, Materials* and *Ecology and environmental quality* are the most considered categories from a quantitative prespective;
- The categories being less considered are *Olfactory comfort,* assessed only by HQE™, and *Resistance to natural disasters*, assessed only by CASBEE for Homes and Detached House, DGNB Core 14, HQE™ Maison Individuelle NEUF and Rénovée;

- A cross comparison of the schemes is not feasible, as the most complete schemes within each system do not share the same purposes. However, restricting to consider groups of schemes oriented to a common field, some quantitative assertions can be stated about the accuracy of the schemes. BREEAM is the most accurate within the fields of New Construction, Commercial and In-Use. HQE™ is the most accurate within the fields of Urban Planning and Refurbishment.
- The most limited schemes are those oriented to the urban context, which neglect the assessment of categories in the scope *Indoor environmental quality.* They are: BREEAM Communities 2012, CASBEE for Cities 2012, HQE™ Infrastructures and LEED® for Neighborhood Development 2009;

Chapter 5

Comparison of two national schemes: *Protocollo ITACA* and BREEAM - Nor

This final chapter aims at presenting and comparing two national schemes: *Protocollo ITACA* (Italy, based on SBTool) and BREEAM - Nor (Norway, customization of BREEAM). A description of the two schemes is addressed, providing information about categories, weighting factors and scoring rate. As for the case of international schemes, a comparison has been performed on the basis of the project type, building type, life cycle phase of the building and a set of re-arranged categories common between the two schemes. For the sake of completeness, the main differences between the original international schemes and the their customized version are also exploited on the basis of the aforementioned criteria.

5.1 *Protocollo ITACA*

The Istituto per l'Innovazione e Trasparenza degli Appalti e la Compatibilità Ambientale, refered with the acronym ITACA, in collaboration with the Conference of the Presidents of the Italian Regions, on 15 January 2004 adopted the SBTool guidelines for creating the so-called *Protocollo ITACA* as a national scheme instituted in all the Italian regions. The intent was to assess in a objective manner the environmental quality of buildings. The aim was to create a common national base according to the different interests of the parties involved in the building development, such as designers, owners and constructors [114].

The national authority in charge of facilitating and promoting the *Protocollo ITACA* is the iiSBE Italia. It supports the adoption of policies, methods and tools and ensures the application of guidelines and maintaining relations with the SBTool international control system. Many regions have customized the national scheme in accordance with local features, adding or removing criteria as needed. This tailoring process is producing a disconnected and not harmonized national framework. This on one hand provides flexibility of the protocol, but on the other side may cause a lack of objectivity, which was one of the main requirements of the assessment tools.

Nowadays the local versions of the tool are available for the regions Marche, Puglia, Umbria, Piemonte, Valle d'Aosta, Friuli Venezia Giulia, Liguria, Lazio e Basilicata. The evaluations in the regional context are given by permitted local societies, like ARPA (Agenzia Regionale Protezione Ambientale) and ITACA itself; nationwide they are temporarily issued by the ITC-CNR and iiSBE Italia.

The latest version, entitled *Protocollo ITACA Nazionale 2011*, was approved by the ITACA managing board and the update arise from the need to adapt the assessment tool to the latest Italian standards in the field of energy and (UNI 11300 series) and for the adjustment to the "National guidelines for energy assessment". This version includes the frames for several structure arrangements: residential buildings, offices, educational, commercial and industrial buildings. For all the other building types not included in this list, the environmental assessment can be developed according to the SBTool procedure. As already mentioned, the *Protocollo ITACA* is strongly based on the SBTool and it can be applied both to new and existing buildings during their entire life cycle, from the design phase towards production, construction and finally refurbishment. The protocol structure is subdivided into categories: Performance Issues, Performance Categories, Performance Criteria and Performance Sub-criteria [115]. The performances are rated on a scale from -1 to +5, where 0 refers to a standard building, representing the current legal state-of-the-art. The score is assigned by comparing calculated indices and benchmarks got in the aforementioned categories.

The rating scale and the interpretation of each rating level are reported in Table 28.

Table 28 *Protocollo ITACA*: interpretation of the rating scale and scores

Scoring scale	Description
-1	Performance less than the current building standard .
0	Minimum acceptable performance defined by current rules, represents the running procedure.
1	Slight improvement of the performance compared to the current rules and running procedure.
2	Moderate improvement of the performance compared to the current rules and running procedure.
3	Substantial improvement of the performance compared to the current rules and common procedure. It can be considered as the best running procedure.

Scoring scale	Description
4	Moderate improvement of the best running procedure.
5	Prominently advanced performance compared to the best running procedure, experimental.

A weighting factor representing the degree of importance within the assessment tool is assigned to each criterion. The Performance Issues and the connected weights are reported in Table 29.

Table 29 *Protocollo ITACA*: Performance Issues and related weighting factors

Categories	Percentage
Outdoor Environmental Quality	5 %
Resources Consumption	45 %
Loadings	20 %
Indoor Environmental Quality	20 %
Quality Service	20 %

For each specific instrument two different evaluation boards are supplied: one is referred only to the site assessment; the other is related to the assessment of the building and its relevance areas. In the illustrative table below, the *Outdoor Environmental Quality* criterion is present in both sheets but it takes into account different assessment areas and categories.

Table 30 *Protocollo ITACA*: outdoor environmental quality evaluation board.

	Site evaluation	Evaluation of the building and its relevance areas
Criterion name	A. Outdoor environmental quality	A. Outdoor environmental quality
Evaluation areas	A.1 Site Selection	A.3 Site Design
Categories	A.1.5 Territorial Reuse A.1.6 Access to public transport A.1.10 Closeness to infrastructures	A.3.4 Bicycles use support A.3.7 Use of local tree species A.3.10 Urban context incidence

5.2 BREEAM Norway

The BREEAM Norway Version 1.0 was developed in 2012 by a large number of volunteer of the Norwegian Green Building Council (NGBC) member companies. The purpose was to increase the environmental standard of Norwegian constructions and mitigate the impact of buildings on the environment. This Norwegian version is an adaptation of the English BREEAM to the local standards and rules. It is an attempt of integrating the different interests of the Norwegian real estate and of the construction sector [116]. SINTEF, on behalf of NGBC, is the body in charge to assure the quality of the assessor review and classification.

The BREEAM - NOR assessment scheme is based upon a credit list on the example of *BREEAM Europe Commercial 2009* and *BREEAM Education 2008*. This list meets Norwegian rules, standards and practice specified in the “Handbook for Environmental Correct Construction”.

The assessment may be done at the end of the following two project phases:

1. The design stage (DS), leading to an interim certificate assessing the building performance as a rule before the construction starts;
2. Post-Construction Stage (PCS), leading to a final certificate of the building performance.

The type of projects that can ben assessed with the BREEAM - Nor are represented in Table 31.

This Norwegian-tailored BREEAM scheme is not designed to assess minor refurbishment of an existing building or a renovation with a change of use.

The types of buildings that can be assessed using the BREEAM - Nor scheme are offices, retails, industrial and education buildings. All the other types of buildings not covered by the scope of BREEAM - NOR could be assessed using the BREEAM Bespoke scheme [116].

The categories taken into account in the BREEAM - Nor are the same of the BREEAM U.K., and are organized in 11 sections and divided into issues. In this case, given the peculiarity of the protocol, it’s possible to furnish the weighting factors and credits related to each category that are necessary for the comparison.

Table 31 BREEAM - Nor: Type of project evaluable and related specifications.

Type of projects	Specifications
Whole new buildings	N/A
Major refurbishments of existing buildings	Thermal elements include walls, roofs and floors Fittings include windows (incl. Roof lights), entrance doors Building services include lighting, heating and mechanical ventilation/cooling and management systems.
New build extension to existing buildings	When assessing only a new-build extension to an existing building, in some BREEAM issues it is necessary to consider services/facilities
A combination of new-build and existing building refurbishment	N/A
New build and/or refurbishments which are part of a larger mixed use building	N/A
Existing building fit-out	An assessment can be carried out on the first fit-out of the shell of a new building/unit or subsequent re-fit of an existing building/unit recognizing the opportunity to improve the environmental performance of the building

Table 32 BREEAM - Nor: categories and credits.

Categories	New builds, extensions & major refurbishments	Building fit-out only	Credits
Management	12.0	13.0	10
Health & Wellbeing	15.0	17.0	14
Energy	19.0	21.0	21
Transport	10.0	11.0	10
Water	5.0	6.0	6
Materials	13.5	15.0	12
Waste	7.5	8.0	7
Land Use & Ecology	10.0	N/A	10
Pollution	8.0	9.0	8
Sum	100.0	100.0	102
Innovation	10.0	10.0	10

5.3 Analysis and comparison

This subsection is focused on the analysis and comparison of the two local systems presented above in Sections 5.1 and 5.2. The used methodology is the same as the one employed in Section 4.1. The items that have been analyzed are the following:

- Project type;
- Building type;
- Phase of the life cycle;
- Scopes.

Table 33 illustrates how SBTool, *Protocollo ITACA*, BREEAM International *New Construction*, BREEAM Europe *Commercial*, BREEAM International *In-Use*, and BREEAM - Nor differ in the assessment of the *Project type* field.

Table 33 Type of project assessed by the selected schemes

Assessment tools	**Type of project**					
	New Buildings	**Major refurbishment of existing buildings**	**New build extension of existing buildings**	**Existing building and fit-out**	**Combination of new-build and existing building refurbishment**	**New build and/or refurbishment which are part of a larger mixed use building**
BREEAM Europe Commercial 2009	•	•	•	•	•	•
BREEAM International New Construction 2013	•	N/A	•	N/A	N/A	N/A
BREEAM - Nor 2012	•	•	•	•	•	•
BREEAM International In-Use 2015	N/A	N/A	N/A	•	N/A	N/A
Protocollo ITACA 2011	•	•	•	N/A	N/A	•
SBTool assessment framework 2012	•	•	•	N/A	•	•

The schemes that result more complete in terms of project type are BREEAM Europe Commercial and BREEAM–Nor, as they cover each type of project. Moreover, BREEAM

International In-Use refers only to the category “Existing building & fit-out”, as it is naturally oriented to existing buildings. Similarly, BREEAM International New Construction is specific for projects involving new buildings or large extensions of existing buildings. An interesting difference can be found in SBTool and *Protocollo ITACA*: although the latter is a customization of the first one, it does not assess “Combination of new-building and existing building refurbishment”. From an accurate observation of the two customizations, it can be inferred that BREEAM–Nor appears more structured than *Protocollo ITACA* as it include two additional evaluation items, namely “Existing building & fit-out” and “Combination of new-building and existing building refurbishment”.

Table 34 shows the difference between the schemes in the assessment of *Building type* field. We can notice that the only two building types that are covered are “Office” and “Industrial buildings”. The most complete scheme is BREEAM International New Construction as it covers all existing categories except *Urban Planning,* which is indeed covered by none of the considered tools. In particular, we can notice that the only clear difference between *Protocollo ITACA* and BREEAM–Nor concerns “Residential buildings”, which does not fit in the field of applicability of the second scheme.

Table 34 Type of building assessed by the selected schemes

Assessment tools	**Type of building**						
	Residential	**Office**	**Commercial**	**Industrial**	**Educational**	**Other type of buildings**	**Urban Planning**
BREEAM Europe Commercial 2009	N/A	•	•	•	N/A	N/A	N/A
BREEAM International New Construction 2013	•	•	•	•	•	•	N/A
BREEAM - Nor 2012	N/A	•	•	•	•	N/A	N/A
BREEAM International In-Use 2015	N/A	•	•	N/A	N/A	•	N/A
Protocollo ITACA 2011	•	•	•	•	•	N/A	N/A
SBTool assessment framework 2012	•	•	•	N/A	N/A	•	N/A

Table 35 reports the data about *Life Cycle Phase of buildings.* According to the table, the "Stage assessment" for BREEAM International In-Use is limited to "Operation and Maintenance". On the other hand, the remaining schemes do not have many differences and refer to the same life cycle phases of the buildings. From a direct comparison between *Protocollo ITACA* and BREEAM –Nor, we can notice that the "Construction" phase is evaluated in the first scheme but not in the second one.

Table 35 Life cycle phase of the building assessed by the selected schemes

Assessment tool	Stage of assessment			
	Pre-design and design phase	**Construction**	**Post Construction phase**	**Operation and Maintenance**
BREEAM Europe Commercial 2009	•	N/A	•	N/A
BREEAM International New Construction 2013	•	N/A	•	N/A
BREEAM - Nor 2012	•	N/A	•	N/A
BREEAM International In-Use 2015	N/A	N/A	N/A	•
Protocollo ITACA 2011	•	•	•	N/A
SBTool assessment framework 2012	•	•	•	N/A

The last point that has been considered in the analysis regards categories and scopes of each assessment tool. While performing the evaluation of data, a particular attention has been devoted to the scopes contained in each category. However, it must be pointed out that sometimes a discrepancy in the definition of elements constituting the categories is encountered. For this reason, the categories have been partially renamed and the sub-categories slightly rearranged in order to allow a more precise and clear comparison between the two schemes. The meaning and the content of each category and subcategory have been already presented in the Section 4.2 of the Chapter 4.

For the sake of completeness, a comparison between the schemes belonging to the same family is reported in

Table 36 and the category “Noise pollution”

Table 37.

Table 36 BREEAM: Scopes evaluated in the International and Norwegian assessment schemes.

	Scopes							
	Energy	Indoor environmental quality	Innovation	Management	Materials and resources	Pollution and waste	Resistance against natural disasters	Site Quality

Assessment scheme	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	Materials Reuse	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																											
Europe Commercial 2009	•	•	•	•			•	•			•	•	•	•	•	•	•	•	•		•	•			•	•		
In-Use International 2015	•		•	•			•	•	•	•		•	•			•	•	•	•	•	•	•			•	•		•
International New Construction 2013	•	•		•	•		•	•	•	•	•					•	•	•	•	•		•			•	•		•
BREEAM–Nor 2012	•		•	•	•		•	•	•	•	•		•		•	•	•	•	•	•	•	•			•	•		•

Focusing on the BREEAM schemes first, we can see in

Table 36 that the scheme with the largest number of scopes taken into account is BREEAM–Nor, while BREEAM Europe Commercial and BREEAM IN-Use assess the same number of categories. BREEAM New Construction results to be the most limited, as it does not consider the categories “HVAC”, “Management”, “Building information and Users Guide” and “Waste water management”. None of the schemes pertain the evaluation of environmental sustainability of buildings in terms of natural disasters or earthquakes.

In the category “Noise pollution”

Table 37, the same comparison is proposed for SBTool and *Protocollo ITACA*. Within the latter, each reported scheme includes both “New Construction” and “Refurbishment”. The evaluation criteria are the same but the corresponding weighting factors are different.

Protocollo ITACA takes into account the same categories in each scheme, expect for “Ecology and environmental quality” and “Acoustic comfort”, which are not included in the schemes for “Residential and Office Buildings” and “Commercial and Industrial Buildings”.

Comparing SBTool with its Italian customization *Protocollo ITACA*, we can see that the second one is more detailed in terms of scopes. In particular, the additional categories “Renewable technologies”, “HVAC”, “Building information and users guide” and “Material reuse” are included. Conversely, SBTool is the unique system that evaluates the category “Noise pollution”

Table 37 SBTool and *Protocollo ITACA*: Scopes evaluated in the each assessment schemes.

Assessment scheme	Scopes																											
	Energy					**Indoor environmental quality**					**Innovation**	**Management**			**Materials and resources**				**Pollution and waste**				**Resistance against natural disasters**		**Site Quality**			
	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	Materials Reuse	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
	SBTool																											
SBTool assessment framework 2012	•			•	•		•	•	•	•				•		•	•		•		•	•			•	•	•	•

Assessment scheme	Scopes																											
	Energy					**Indoor environmental quality**					**Innovation**	**Management**			**Materials and resources**				**Pollution and waste**				**Resistance against natural disasters**		**Site Quality**			
	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	Materials Reuse	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
Protocollo ITACA																												
Commercial Buildings 2011	•	•	•	•	•		•	•		•			•		•	•	•	•			•	•			•	•		•
Industrial Buildings	•	•	•	•	•		•	•		•			•		•	•	•	•			•	•			•	•		•
Educational Buildings 2011	•	•	•	•	•		•	•	•	•			•		•	•	•	•			•	•			•	•		•
Office buildings 2011	•	•	•	•	•		•	•	•	•			•		•	•	•	•			•	•			•	•		
Residential Buildings 2011	•	•	•	•	•		•	•	•	•			•		•	•	•	•			•	•			•	•		

In Table 38 a comparison between BREEAM–Nor and *Protocollo ITACA* is proposed to highlight the main differences. As already mentioned referring to the category "Noise pollution"

Table 37, the family of schemes belonging to *Protocollo ITACA* does not show particular differences, as the categories taken into account are very similar.

Focusing on the Norwegian customization of BREEAM, we can see from the table that this scheme includes a larger number of categories. In particular, differently from *Protocollo ITACA*, BREEAM–Nor consider “Acoustic comfort”, “Innovation”, “Noise pollution” and “Light pollution”. The only category that is present in *Protocollo ITACA* and not in BREEAM–Nor is “Renewable technologies”.

Table 38 *Protocollo ITACA* and BREEAM - Nor: Scopes evaluated in the each assessment schemes.

	Scopes							
	Energy	**Indoor environmental quality**	**Innovation**	**Management**	**Materials and resources**	**Pollution and waste**	**Resistance against natural disasters**	**Site Quality**

Assessment scheme	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	Materials Reuse	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 - Nor 2012	•		•	•	•		•	•	•	•	•		•		•	•	•	•	•	•	•	•			•	•	•
Protocollo ITACA																											
Commercial Building	•	•	•	•	•		•	•		•			•		•	•	•	•			•	•			•	•	•
Industrial Buildings 2011	•	•	•	•	•		•	•		•			•		•	•	•	•			•	•			•	•	•
Educational Buildings 2011	•	•	•	•	•		•	•	•	•			•		•	•	•	•			•	•			•	•	•
Office buildings 2011	•	•	•	•	•		•	•	•	•			•		•	•	•	•			•	•			•	•	
Residential Buildings 2011	•	•	•	•	•		•	•	•	•			•		•	•	•	•			•	•			•	•	

Conclusions

In this chapter of the study two national assessment schemes has been analyzed. Mimicking the approach of the previous chapter, the following items have been taken into account: *project type*, *building type*, *life cycle phase of the building* and *scopes*. Based on the evaluation of data and interpolating the results discussed previously, the following conclusions can be stated:

- In the *project type* item, BREEAM Europe Commercial e BREEAM–Nor seem to be the most complete schemes as they take into account every type of project;

- SBTool and *Protocollo ITACA* do not assess the same project types and differ in the item *Combination of new-build and existing building refurbishment*, which is considered only by the former;
- Comparing *Protocollo ITACA* with BREEAM–Nor, the latter is more complete, since the former does not assess *Existing building and fit-out* and *Combination of new-build and existing building refurbishment*;
- Regarding the *building type* field, none of the schemes cover the assessment of the Urban Planning;
- The building types *Office* and *Industrial Buildings* are analyzed by both the scheme;
- BREEAM New Construction results to be the most complete in terms of *building type*, as it considers all the categories, except *Urban planning*;
- The category *Residential Buildings* constitutes the difference between BREEAM–Nor and *Protocollo ITACA*, as it is not assessed by the former;
- Regarding the *life cycle phase of the building*, we can notice that BREEAM International *In-Use* is intrinsically limited to the *Operation* phase;
- Within the two families of schemes, except for the aforementioned BREEAM International *In-Use*, there are no significant differences in the evaluation of the *life cycle phases*;
- Restricting to BREEAM–Nor e *Protocollo ITACA*, the *Construction* phase is not considered by the former;
- Comparing the schemes of the BREEAM group, we can see that the most complete is BREEAM–Nor featuring 21 categories, while the most limited is BREEAM New Construction covering 18 categories;
- Referring to the categories belonging to *Protocollo ITACA*, *Ecology and environmental quality* is not evaluated by *Protocollo ITACA* for Residential Buildings and Office Buildings and *Acoustic comfort* is not evaluated by *Protocollo ITACA* for commercial buildings and industrial buildings;
- None of the considered schemes assesses *Resistance against natural disaster*;
- Comparing the scopes of BREEAM–Nor and *Protocollo ITACA*, the latter evaluates a larger number of categories and, therefore, it can be considered the most complete.

Conclusions

In this thesis we have presented an overview of the available environmental assessment schemes in the building sector. The core of the work is a comparative analysis of such schemes. The environmental assessment schemes are technical instruments that have been developed with the aim of evaluating the energy and environmental performances of buildings. In recent years, a growing interest in sustainability and sustainable development has been registered due to the urgent requirement of worldwide reduction of greenhouse gas emissions for the safety of our planet and the health of our society. This had a remarkable impact also on the building and construction industry and, consequently, a wide array of assessment schemes has been developed, with different purposes and features. The present study is motivated by the need of identifying such differences to better understand the assessment schemes. Beside a survey of all existing schemes, a choice of six schemes is made in view of the analysis: Building Research Establishment Environmental Assessment Methodology (BREEAM), Comprehensive Assessment System for Built Environment Efficiency (CASBEE), Deutsche *Gesellschaft für Nachhaltiges Bauen* (DGNB), *Haute Qualité Environnementale* (HQE™), Leadership in Energy and Environmental Design (LEED®) and SBTool. The data have been collected from technical manuals, official websites and, sometimes, through direct relationships with agents from the technical or administrative board of the systems. In this regard, we point out that some challenges have been faced during the data acquisition process. User manuals are not always available and information, even though are generally public disclosed, often appear very fragmentary. Moreover, in certain cases, such as for DGNB and HQE™, most of documents have been provided in the national language and only very little information in English is accessible to international users.

The analysis has been carried out taking into account several fields: *project type, building type, life cycle phase, rating and scopes*. These allow deducing a series of interesting features of the schemes. However, based on these criteria, it is not possible to identify which of the schemes is the best. Indeed some schemes are naturally oriented to specific building or construction purposes and therefore they consider a limited range of categories that are used for the assessment: this limits the applicability of the scheme, but it does not necessarily reduce its reliability and capability. On the other hand, there are schemes that assess a large number of categories and hence may be considered complete to some extent, even though not always comparable between each other as they may refer to different typologies of constructions. Some groups of schemes devoted to a common field can be isolated with the aim of comparing their accuracy. BREEAM is the one that assesses the largest number of categories in the fields New Construction, Commercial and In-Use, while HQE™ is the most accurate within the fields of Urban Planning and Refurbishment. Based on the comparison performed in Chapter 5, the local customization of BREEAM results to be more accurate than the local customization of SBTool. As a general, but possibly reductive, conclusion we can state that the whole set of schemes of the BREEAM family features probably the widest range of suitable fields of applicability.

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