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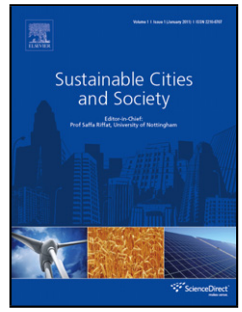

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A COMPARATIVE ANALYSIS OF SUSTAINABLE BUILDING ASSESSMENT METHODS

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Highlights

- The prevailing building sustainability assessment methods were reviewed
- Different methods were divided into groups
- Each groups of methods and Level(s) was studied
- Level(s), currently in the testing phase, is the most complete method identified in this study

Abstract

Since the advent of the first sustainability assessment method, TRYNNS, a large number of widely differing methods have been developed to assess, rate and certify the sustainability of different types of buildings. This study sets out to review, identify, classify and compare today's main assessment methods by analysing their characteristics, structure, scope of application and approach. As a result, 101 current methods have been identified and assigned to 3 groups: systems, standards and tools, plus a recently approved instrument called Level(s). The 36 most representative methods identified have been selected, and have been compared using 4 variables: phase of life cycle applied; sustainability aspects assessed; categories considered; and the type and status of the project assessed. The results have shown that each of the methods separately does not assess all aspects of a sustainable building. Many assess energy and the quality of the interior environment, while few assess more recent social and economic aspects. The considerable number of methods considered and the in-depth analysis performed in this study give extremely valuable insight into the existing evaluation framework, and allows agents to select the method that best responds to their needs.

Keywords

sustainable building; Level(s); systems; standards; tools; sustainable building assessment methods

1. Introduction

One of the main sectors triggering the acceleration of climate change and the depletion of natural resources is the construction industry. Each cycle of this activity – construction, use, and finally demolition and disposal, creates a significant environmental burden, which varies considerably depending on the type and location of each building (Sandanayake, Zhang, & Setunge, 2018). Growing construction in urban areas has a significant impact on the environment, the economy, public health (Darko, Chan, Ameyaw, He, & Olanipekun, 2017) and wellbeing in cities (Macías & García Navarro, 2010); it is responsible for 40%-50% of all energy use, doubling its consumption between 1973-2012 (Carpio, Zamorano, & Costa, 2013) and increasing anthropogenic greenhouse gas (GHG) emissions (Miller, Doh, Panuwatwanich, & van Oers, 2015); it consumes 30% of raw materials, 25% of global water (Giannetti, Demétrio, Agostinho, Almeida, & Liu, 2018) and 17% of the world's freshwater (Dixit, Culp, & Fernández-Solís, 2013); it occupies 12% of the ground surface (Dong & Ng, 2015); and it generates 25% of solid waste worldwide and 40% of solid waste in developed countries (Yılmaz & Bakış, 2015).

This issue has led authorities, organisations, professionals and citizens to call for a sustainable construction industry that can address the environmental and health problems that arise from buildings, reduce the impact of the industry on the environment and on people (Doan et al., 2017), and mitigate the environmental footprint of the built environment (Dong & Ng, 2015). These three dimensions (environmental, social and economic) form the framework for the philosophy of sustainable development.

To reach this goal, countries around the world have developed many methods, more than 600 in total, along with the rapid development of sustainable buildings (Doan et al., 2017). New methods are continuously being proposed, and the most widely used ones are updated on an annual basis. Examples of this include assessment methods such as the Building Research Establishment Environment Assessment Methodology (BREEAM), HQE, Verde, Protocollo ITACA, PromisE, Økoprofil, Nordic Swan, Lider A, DGNB; standards, including Passivhaus, Built Green and Net Zero Energy (NZE); and environmental assessment tools, such as those based on life cycle assessment (LCA) methods, including ATHENA, BEES, LISA, SOFIAS, ENVEST, ECO-quantum, or on the performance of energy systems, such as Energy Plus, Transient System Simulation Tool (TRNSYS), Ecotect and Calener. Another important tool is Level(s), an instrument recently launched by the European Commission, which is currently undergoing testing. It has been developed to be used throughout Europe for the purpose of creating a new

European Union (EU) framework for the sustainability of buildings (Dodd, Cordella, Traverso, & Donatello, 2017b).

An analysis of the literature reveals studies comparing the most widespread, internationally implemented methods. For example, Asdrubali et al. (Asdrubali, Baldinelli, Bianchi, & Sambuco, 2015) compared the LEED and ITACA environmental rating systems by applying both methods to two residential buildings located in Italy; Seinre et al. (Seinre, Kurnitski, & Voll, 2014) compared certain indicators and their levels of LEED and BREEAM; Mattoni et al. (Mattoni et al., 2018) carried out a critical review using a methodological approach to evaluate the differences between CASBEE, GREEN STAR, BREEAM, LEED and ITACA, in order to understand which aspects have more influence on the final efficiency rating of each system, and to give users a clearer understanding of the aspects included; Montteroti (Monterotti, 2013) carried out a systematic analysis of the problems of CASBEE, GBTOOL, ITACA and LEED, based on the same common indicators that could serve as a basis for the design of a new tool; Doan et al. (Doan et al., 2017) focussed on BREAM, LEED, CASBEE and GREEN STAR NZ; Haapio and Viitaniemi (Haapio & Viitaniemi, 2008a) carried out a literature review and rough comparison of sixteen methods, including BEES, TEAM, ATHENA, BEAT or ENVEST; and Syahrul et al., (Kamaruzzaman, Lou, Zainon, Mohamed Zaid, & Wong, 2016) explored the prominence of different assessment schemes, the ones that were mentioned most frequently in the literature, and the ease of access to assessment manuals, comparing BREEAM, LEED, CASBEE, BEAM, GBLS, HQE, GREEN STAR, MARCA VERDE, GBI and MYCREST; while the Department of Environment, Territorial Planning and Housing of the Basque Government classified 34 methods (IHOBE Sociedad Pública de Gestión Ambiental, 2010), and compared BREEAM, LEED, CASBEE, GREEN GLOBES, GREEN STAR and HQE with their own Sustainable Building Guidelines.

The aforementioned studies show that although these methods have a common goal, namely, reduction of environmental impact derived from construction, their analysis reveals important differences in terms of the impacts analysed and their scope of application. Thus, sustainable buildings in different countries are designed and built according to local climatic conditions and the needs of the local population. Furthermore, none of these methods can individually perform a full study over the complete life cycle of a building. Consequently, it is not possible to compare buildings that are sustainable in themselves with other similar buildings that are not. They also show the impossibility of standardization and development of instruments. Furthermore, the methods have been analysed individually, rather than in a group, and no studies have included the most recent Level(s) method. In addition, no study has been found that compares all the most commonly used methods.

For all the above reasons, the objective of this study has been the comparative analysis of the current status of sustainable building assessment methods. The study presented here contributes to the existing body of knowledge by highlighting trends and patterns in the field of research into sustainable building assessment methods. This will allow us to, among other things, identify the main similarities and differences between these methods, examine whether they fully assess all aspects of sustainability in each project, and show which stages of the life cycle they cover. In addition, this analysis will include the Level(s) method for the first time, thus giving a complete overview of current trends in building assessment.

2. Method

For the purposes of this study, a series of specific objectives were developed that shaped the stages of the established working methodology (Figure 1): (i) a quantitative review by means of a review of the literature of current assessment methods and their classification into groups; (ii) a comparative analysis between groups; (iii) a comparative analysis between the methods included in each group; (iv) a comparative analysis between the traditional methods.

2.1. Identification and classification of assessment methods in groups.

The identification of assessment methods should be based on relevant published documents such as books, journal articles, websites and manuals on sustainability assessment in building. Once identified, different criteria were analysed for their classification. For example, the ATHENA Sustainable Materials Institute introduced the Athena classification, which divides the methods into three levels: (i) tools for comparing products and sources of information; (ii) design of whole buildings and decision-making support tools; and (iii) assessment frameworks or systems for whole buildings (Haapio & Viitaniemi, 2008a). The IEA project Annex 31, Energy Related Environmental Impact of Buildings, classified the methods into five categories: (i) Energy modelling software; (ii) Environmental LCA tools for buildings and building stocks; (iii) Environmental assessment frameworks and rating systems; (iv) Environmental guidelines or checklists for design and management of buildings; and (v) Environmental product declarations, catalogues, reference information, certifications and labels (Haapio & Viitaniemi, 2008a).

Finally, in this study, we have considered three groups, which correspond with the classification created by the Public Environmental Management Agency of the Basque Government. This criterion was chosen because it is the most recent system, and takes into account common characteristics, objectives and scope of application (IHOBE Sociedad Pública de Gestión Ambiental, 2010). The system has the following three levels:

- **Group I: Building Sustainability Assessment Systems.** These assessment systems (henceforth, Systems) are methods which assess the level of sustainability of a building and its systems or subsystems, as well as classifying and certifying the building based on a series of predefined sustainability parameters or categories (environmental, economic and social) (IHOBE Sociedad Pública de Gestión Ambiental, 2010), which are constantly updated and provide a rating system for sustainable buildings. They are voluntary and educational systems, which are powered by government agencies or developed by non-government organisations. These methods assess a large number of sustainable aspects and types of buildings. Some of them only set out to assess or classify the level of sustainability; others go further, and enable the certification of the building by a qualified assessor, who has usually been trained by the agency granting the certification, which is costly. Given that most of the actions that have an impact on a building's use phase are adopted during the design phase, the vast majority of Systems focus on the assessment of new-build constructions, and study the entire life cycle of the building. Therefore, they give an understanding of efficient, environmentally-friendly buildings (Awadh, 2017a), although in some cases, these Systems may also include urban development projects (Bernardi, Carlucci, Cornaro, & Bohne, 2017).
- **Group II: Sustainable Building Standards**. Sustainable building standards (henceforth, Standards) are methods, also of voluntary application, which call for minimum performance requirements to determine whether a certain building and/or its systems and subsystems comply or fail to comply with requirements (Vega Clemente, 2015). In this case, they do not categorise sustainable buildings, and are usually accepted as being synonymous with good practices. Standards do not cover the complete study of the life cycle of the building, nor do they include urban development projects. Instead, they generally focus on the use phase of the building, particularly energy-related aspects, and leave aside other environmental, social and economic issues. To this end, they establish energy consumption and insulation limits, attempting to minimise energy needs inside buildings and thereby reduce the

associated emissions. They usually provide a catalogue of building systems or solutions to enable constructors to comply with these requirements.

- **Group III: Assessment Tools.** Assessment tools (henceforth, Tools) are not geared towards certification, classification or compliance with minimum requirements, but towards providing the designer with a support tool for the sustainable design of the building and to improve the building's rating when it is assessed using any of the foregoing Systems or Standards. Although there is no need to have an associated Tool, many of the methods included in the groups described above may call for the input of data values that require the use of Tools. These are computer programs designed to support the other methods, and are not always necessary, so they are not able to generate a full assessment. Most of these methods facilitate the selection of building designs, building materials and local service options (energy supply, waste management and transport type) during the design phase (Ali & Al Nsairat, 2009). Two core types of Tools tend to be distinguished:

  (i) Those based on the Life Cycle Assessment which, with greater or lesser scope, place greater emphasis on the environmental impacts of the building than on the environmental aspects in which it operates.

  (ii) Those that assess the energy efficiency of buildings, some of which allow for the energy modelling of buildings.

2.2. Comparative analysis between identified groups.

As indicated above, countries around the world have developed many methods, more than 600 in total, along with the rapid development of sustainable buildings (Doan et al., 2017). Due to this high number of methods, the comparative study will be carried out in two phases (Figure 1).

In a first phase, the groups identified will be compared based on a series of general characteristics that will include (Figure 1): number of buildings and/or m^2 evaluated, endorsement by the competent authority of the country of application, quality assurance and year of updating. We consider that limiting the methods analysed using these criteria will not compromise the validity of the study, and will allow us to select the most representative method within each group. In a second phase, a more complete comparison will be carried out in order to clarify the scope of their application. To this end, the following four variables have been identified and defined (Figure 1):

(i) **Phase of the life cycle.** The life cycle of a construction project could be defined as the period that spans from the initial planning to the total disposal of the building. The review of the literature shows the different phases for life cycle analysis as the production of building materials, construction, use and operation, demolition (Kofoworola & Gheewala, 2008), maintenance and disposal (Haapio & Viitaniemi, 2008a). For this purposes of this study, a more complete classification was considered, including the aforementioned seven phases, to consider the design phase, since the assessment instruments are more useful during this phase, because they incorporate environmental, social and economic impacts into the design process to minimise impact, and give an insight into and redesign the performance of the building before the start of construction (Ding, 2008).

(ii) **Aspects of sustainability assessed.** Traditionally, sustainability assessment methods focus solely on the environmental aspect. However, more recent developments reflect the shift in sustainable building assessment towards the recognition of social and economic aspects (Petrovic-Lazarevic, 2008; Zuo, Jin, & Flynn, 2012). Consequently, the three indicated aspects were considered for this variable: environmental, social and economic.

(iii) **Assessment categories considered.** The assessment categories are each of the study areas considered by the different methods, in which the various sustainable aspects are addressed. The review of literature shows different assessment categories, such as site selection, resources, energy, innovation, indoor environmental quality and materials used, among others (Al-Jebouri, Saleh, Raman, Rahmat, & Shaaban, 2017a; Chandratilake & Dias, 2015; Yu, Li, Yang, & Wang, 2015). Based on this review, ten categories were identified to compare and contrast the way in which these are addressed in each Group. The definition and study areas that include these categories are shown in Table 1. Of note is the inclusion of category (C10) Adaptation to Climate Change, since some of the identified methods are currently channelling all their efforts into incorporating new challenges that not only mitigate, but also adapt the building to climate change by minimising its exposure to the potential negative effects of these changes. This means proposing, among many other solutions, stronger constructions designed for extreme temperatures, the construction of coastal infrastructure to mitigate the impact of climatic phenomena, and territorial planning to identify places of high vulnerability, etc., in other words, resilient planning and design actions. Resilience is the ability of a building to adapt to climate change and natural disasters, along with its ability to recover in a timely and efficient manner without incurring damage (Champagne & Aktas, 2016). There is a firm relationship between sustainability and resilience; they complement one another, and set out to curb future environmental repercussions through cause and effect, respectively.

(iv) **Type and status of projects where assessment is applied.** Different authors have included this variable in their studies. For example Illankoon et al. (Illankoon, Tam, Le, & Shen, 2017) included new-builds as part of the assessment of the methods; Doan et al. (Doan et al., 2017) also included neighbourhood development manuals; Haapio and Viitaniemi (Haapio & Viitaniemi, 2008a) specified that the methods can also be used to assess existing buildings, buildings undergoing refurbishment, and construction products and components. For the purposes of this study, we have considered identifying types of project (building, developments and parts or components of a building) and construction statuses (new-build or existing building) where the identified methods are applied.

2.3. Comparative analysis of assessment criteria among methods

Once the above variables have been identified, at the Group level, the differences between the methods in each category will be analysed. To this end, a set of criteria will be taken into account that are required for a building and/or a project to be sustainable (Illankoon et al., 2017). These must be measurable, mutually independent, and must refer, whenever possible, to qualities or aspects related to the various environmental, economic and social aspects, which may be quantitative or qualitative (Al-Jebouri, Saleh, Raman, Rahmat, & Shaaban, 2017b); they must also be evaluable according to the life cycle phase. Taking into account the criteria requirements, we reviewed the manuals, instructions and guidelines of the different methods used in each of the ten categories considered (Table 1). This enabled us to identify, categorise and standardise the criteria applied to the 35 representative methods of the three groups considered. The set of criteria identified has a critical impact on the study of building performance (Lu, Geng, Liu, Cote, & Yu, 2017) and will influence the decision-making process of decision makers.

3. Results

3.1. Identification and classification of assessment methods in groups.

After a review of the literature, a total of 101 methods were identified and included in Table 2, which gives a general description of the method, including region and country of application, year of launch, organisation in charge, and number of certified buildings.

Of the identified methods, 101 have been classified into the three groups studied (I, II and III). The last method, Level(s), due to its characteristics, cannot be included in any of the previous groups. It is a new voluntary assessment framework launched by the European Commission to create a new European Union (EU) framework to improve sustainability and steer demand towards better buildings in Europe (Dodd et al., 2017b).

Level(s) is the result of widespread research with the industry and the public sector, and is a means of designing and building sustainable buildings, based on the main methods of the three previous groups. It provides a set of common indicators and metrics to measure the performance of buildings from all aspects of sustainability throughout their life cycle, introducing the concept of circular economy and adaptation to climate change, shifting away from the linear economic model of 'take, make and waste' (Dodd, Cordella, Traverso, & Donatello, 2017a), and thereby facilitating comparison between sustainable buildings within the EU. Level(s) objectives are: (i) sensitise the general public, developers and public procurement services about the need to have better buildings and increase the demand for them; (ii) increase knowledge about the efficient use of resources in the built environment in order to foster better decision-making processes by designers, architects, developers, construction companies, manufacturers of construction products, investors and real estate owners; and (iii) provide a common approach in the EU to assess the sustainability of buildings and the built environment. The flexible indicator can also be incorporated into new and existing assessment systems. Figure 2 provides an overview of the macro-objectives, indicators and scenarios that are part of Level(s). There are six in total, laying down objectives in terms of environment, health and wellbeing, cost, value and risk. Based on these objectives, a series of indicators derived from existing instruments and standards were developed (Dodd et al., 2017b), while the framework is compatible with the use of three levels of performance assessment that may be carried out using these indicators:

- The first level, the assessment of common performance, provides common units of measurement and basic calculation instruments that can be used directly by professionals or easily adopted by the creation of assessment systems, information tools for investors and the public sector.
- The second level, the assessment of comparative performance, is aimed at professionals who wish to make significant comparisons between functionally equivalent buildings.
- The third level, the assessment of optimised performance, provides the most advanced use of each indicator, including more precise calculations and modelling of the design and performance, in order to anticipate future costs, risks and opportunities throughout the life cycle. In some cases, the framework also allows for the use of calculation methods from existing methods.

Given the importance that Level(s) will have in Europe, it has been included in this study as a single method (Figure 3), which will allow comparison with other methods.

3.2. Comparative analysis of methodological groups

3.2.1. General analysis of methods

In the first phase, we will analyse the general characteristics of the methods included in this study. To do this, we will compare their evolution over time in terms of their development and area of application.

An analysis of the timeline of sustainable building assessment methods, included in Table 2, shows an uneven trend, in terms of both the timeline and the group to which they belong, as shown in Figure 4. The analysis shows three key moments in the evolution of the methods: from the implementation of the first instrument up to the early 1990s, when few methods had been developed, due in part to the lack of knowledge about the concept of sustainable building; the introduction in 1990 of the BRE Environmental Assessment Method (BREEAM), and the advent of methods that took into account the social and economic aspect of construction, in contrast to earlier methods that only considered its environmental effects; and 2000, coinciding with the expanded scope of application of the famous Leadership in Energy and Environmental Design (LEED) system, when a large number of methods began to appear. This marked increase can be attributed to the growing recognition of sustainable buildings among industries and construction authorities around the world, as well as to the positive reception and manifestation of the three pioneering methods. Finally, Level(s), the most recent method, currently in a trial period, could mark a turning point in the evolution of methods. If we observe evolution from the point of view of the groups (Figure 4), it can be seen that Systems, followed by Tools, are the most widely developed methods, especially since 2000; in contrast, the number of Standards has remained more or less steady. Despite a relatively brief history, the creation of environmental assessment methods has attracted the attention and interest of academia (Haapio, 2012); and regardless of the date of their initial launch, most of the methods have evolved over time, incorporating the latest technologies, regulations and practical experience (Yu et al., 2015).

Analysing the organizations responsible for the development of the methods, Table 2 shows they have been developed by various non-governmental organisations (NGOs), research institutes, universities, private companies, etc., with 70% of the Systems developed and administered by Green Building Councils (GBC), which are independent non-profit structures made up of companies and organisations in more than 70 countries that are members of the global network of the World Green Building Council (WGBC), which was set up to coordinate the efforts of Green Building Councils around the world. In the case of Tools and Standards, most have been developed by research institutes, universities or private companies.

On analysing the scope of application of the groups, Figure 5 shows that Systems are the most widespread on a global level, with a strong presence in Europe, North America, South America and Asia. They are followed by Tools, with a similar scope, except in Asia. Standards is the least widespread group, being located in North America and Europe. Finally, Level(s) only covers Europe. It can be seen that assessment methods are scarce among less economically developed countries, such as in Africa and Asia, indicating that the higher cost of constructing sustainable buildings has become a major obstacle to encouraging these countries to construct sustainable buildings. The main problem, as Jha et al. (Vyas & Jha, 2018) point out, is that energy saving, indoor air quality and other sustainability factors are not taken into account during the design phase, and only become evident once the building is in use.

3.2.2. Comparative analysis between groups

Given the number of methods identified (Table 2), the most representative ones from groups I, II and III were selected according to the number of buildings and/or m^2 assessed, endorsement from the competent authority of the country of application, quality assurance background, and year of update. We consider that eliminating methods based on these criteria will not compromise the validity of the study. As a result, 35 methods were selected, which appear shaded in Table 2; of these, 21 are Systems, 4 are Standards and 10 are Tools.

In order to compare groups I, II and III, their main characteristics were analysed using the four variables identified and defined in the previous section: (i) phase of the life cycle for application; (ii) aspects of sustainability assessed; (iii) categories considered; (iv) type and project status where assessment is applied. In this study, Level(s) was included as a single instrument, not in a group, and therefore has not been included in this comparative phase.

3.2.2. (i) Phase of the life cycle in which assessment is applied

The number of phases considered in the methods analysed is very varied. It can be observed in Figure 6a that regardless of the group to which they belong, the phase of use is included in most (97%) of the methods analysed; in contrast, the demolition phase is only present in 26% of the methods.

Analysing the data according to Group (Figure 6a), the number of phases consideration differs. The methods in Group I (Systems) consider the greater number of phases, so all of them include the phases of design, production, construction and use, while the phases of disposal, maintenance and demolition are considered in 71%, 48% and 14% of them, respectively. By contrast, Group II (Standards) only considers two phases (design and use), both of which are present in all the methods included in this group. Finally, all the methods of Group III (Tools) include the phase of production and maintenance, 90% of them include the phase of use, 80% include construction and disposal, 60% include demolition, and only 20% include design.

3.2.2. (ii) Sustainable aspects considered

Figure 6b shows the percentage of methods, regardless of the group to which they belong, that take into account the three aspects of sustainability: environmental, social and economic. From the point of view of sustainable aspects, it can be observed that the environmental aspect is present in all methods, to a greater or lesser extent, followed by the economic aspect, closely followed by the social aspect. It is important to point out that even if a method considers different aspects (environmental, social or economic) this does not mean that it includes all the parameters required by an unquestionably sustainable building.

Analysing the data according to Group (Figure 6b), the number of aspects considered also differs. The methods included in Group I (Systems) are the only ones to consider all three aspects. In contrast, Group II (Standards) only considers the environmental aspect. In the case of Group III (Tools), all the methods consider the environmental aspect, none consider the social aspect, and only 9% consider the economic aspect.

3.2.2. (iii) Assessment categories

As in the case of the variables above, the number of categories considered in the analysed methods varies greatly. Figure 6c shows that regardless of the group to which it belongs, none of the categories are present in all the methods, with (C4) Energy being present in 94%, whereas (C9) Circular Economy is only considered in 6%. Finally, it can be observed that the criterion (C10) Adaptation to Climate Change is not considered in any of the methods, as commented previously, because even though developers are updating the different versions, it has not so far been included.

Analysing the data according to Group (Figure 6c), the number of categories considered also differs, as occurs in the variables analysed above; thus, all the methods included in Group I (Systems) cover the categories (C1) Site and Sustainable Development, (C2) Water, (C3) Materials and Resources, (C4) Energy and (C5) Indoor Environmental Quality, whereas categories (C6) Innovation, (C7) Social and Economic, (C8) Quality of Service and (C9) Circular Economy are present in 63%, 53%, 32% and 11% of the

Systems, respectively. At the opposite extreme is Group II (Standards), which only considers categories (C4) Energy and (C5) Indoor Environmental Quality, albeit in all the methods included. Finally, in the case of Group III (Tools), it can be observed that only five of the ten categories are considered, with (C2) Water and (C4) Energy being the most ubiquitous, in 80% of cases, followed by (C3) Materials and Resources, whereas only 30% and 20% of the methods of this group cover (C7) Social and Economic and (C5) Indoor Environmental Quality, respectively.

3.2.2. (iv) Type and status of projects where assessment is applied

Analysing the data from the perspective of the type and status of projects where assessment is applied, it can be observed in Figure 6d that none are present in all the methods, regardless of the group to which they belong. New-builds are the most widely considered, in 92% of the identified methods, whereas only 11% of methods assess components or parts of a building.

Depending on the method-related group, the level of consideration of the type and status of projects also differs, as indicated in Figure 6d. All methods in Group I (Systems) are applied to both existing buildings and new-builds, whether private residences, blocks of flats, office buildings and other buildings, while only 43% of the systems assess neighbourhoods. In contrast, none of the methods in this group cover components or parts of a building. In the case of Group II (Standards), we can see that none of the methods in this group consider neighbourhoods, and only one of them covers components or parts of a building, while all of them assess existing buildings and new-builds, whether residential, office buildings or other types of buildings. None of the methods identified in Group III (Tools) cover neighbourhoods, as in the case of Standards, while 70% of them assess new-builds, and only 30% of Tools consider components or parts of a building.

3.3. Comparative analysis of assessment criteria among methods

In the foregoing section, we drew attention to the differences between Groups I, II and III. However, methods also differ within the same group, so a detailed analysis will be carried out below. In each category considered, an analysis was made of the included criteria, making it possible to compare the methods in each groups. A comparative analysis of Level(s) with traditional methods has been included, because its characteristics cannot be included in any of the previous groups.

3.3.1. Comparative analysis of groups

Taking into account the criteria requirements, and based on the established methodology, 150 criteria were identified for the ten categories considered and summarized in Table 3. Given the sheer scale of the results obtained from this analysis, in this study we have only analysed the 32 criteria belonging to category (C1) Site and Sustainable Development in Group I (Systems) (Table 4). This process was applied to all the criteria, categories and groups, giving the results shown in Figures 7 and 8, and discussed below.

3.3.1.1. Group I: Systems.

As explained above, by way of example, Table 4 includes the relationship of each system with the 32 criteria belonging to category (C1) Site and Sustainable Development. In this table, it can be seen that none of the Systems include all the criteria of the category considered, although all of them consider more than half, except for Verde, which only considers 42%. DGNB is the System which considers the most criteria, 82% in total. Specifically, the criteria which are present in all the methods are: "use of vegetation as shade" and "accessibility to public transport", while the criterion "location without volcanic risk" is only considered in BREEAM.

This analysis was repeated for the remaining ten categories in order to obtain the total percentage of criteria included in the methods in Group I (Systems), giving the results shown in Figure 7. It can be observed that the average percentage of criteria present in the methods of this group is 62%, with a maximum of 69% in LEED and a minimum of 41% in Verde. However, it was observed that all these Systems include criteria related to thermal and acoustic comfort; to the quality of lighting and air; to water usage, quality, efficiency and savings; to the reduction of energy consumption, and to the monitoring and use of energy-efficient systems. This is explained by the fact that these methods have been designed, in part, to adapt sustainable buildings to the wellbeing of the end user.

On analysing the presence of criteria for each of the categories (Figure 8), it was observed that those corresponding to categories included in the most recent sustainable building concepts, such as (C9) Circular Economy, are, at 5%, the least prevalent. In the remaining cases, they range from 46% in category (C7), Social and Economic, and 77% in categories (C2), Water, and (C5), Indoor Environmental Quality. Once again, it is clear that the social and economic aspects are the least developed, as these have only recently have been included in sustainability, and are the most difficult to assess.

3.3.1.2 Group II. Standards

From the point of view of the methods in this group, Figure 7 shows that none of the analysed Standards contain all the criteria. The presence of criteria in all the Standards hovers around 20%. From the point of view of the criteria, analysed by categories, as can be seen in Figure 8 that Standards only considers two categories, (C4) Energy and (C5) Indoor Environmental Quality, with 76% and 55% respectively, which underlines the greater concern of Standards for energy efficiency, as opposed to user wellbeing.

3.3.1.3. Group III. Tools

As in the previous groups, none of the analysed Tools contain all the criteria (Figure 7). In this case, the average percentage of criteria present is 22%, with EcoEffect, which contains 38% of the criteria, being the most complete, while Beat 2002 only contains 9% of the total criteria.

Analysing the data according to criteria and their corresponding categories (Figure 8) shows that this group only contains five, with criteria pertaining to (C4) Energy being the most prevalent, in 55% of Tools. In contrast, only 4% of criteria, on average, from category (C6) Social and Economic are considered by the methods in this group. This again underlines the greater concern of Tools for energy efficiency, as opposed to social and economic aspects (Haapio & Viitaniemi, 2008a).

3.4. Comparative analysis of Level(s) with traditional methods

As indicated above, the final method included in this study was Level(s), which due to its characteristics cannot be included in any of the previous groups. However, given the importance that this instrument will have in Europe, we compared Level(s) and a representative method from each of the three foregoing groups using the identified variables (phase of life cycle for application; aspects of sustainability assessed; categories considered; and type and status of projects where assessment is applied). The three methods were selected based on the number of buildings and/or m^2 assessed, endorsement from the competent authority of the country of application, quality assurance background, and year of update. As a result, we selected LEED version 4.0 as the representative System, Passivhaus as the representative Standard, and ATHENA™ as the representative Tool. LEED version 4.0 (LEED v4) is the most used System worldwide (Bernardi et al., 2017), with presence in more than 165 countries and territories (“LEED | USGBC,” n.d.); Passivhaus is the Standard with the greatest impact;

and ATHENA™ (Cole, 2006) has more than 1200 different combinations of structural and enclosure models, enabling rapid assessment and comparison of the environmental implications involved in the development of a new building (or part of it).

In order to make this comparison, Table 5 identifies the relationship between the previous variables and methods, while Figure 9 highlights the percentage of the scope of each method according to the variables identified. The results obtained are discussed below.

(i) Phase of the life cycle in which assessment is applied

As shown in Figure 9, Level(s) assesses all the identified phases, in contrast to the Passivhaus Standard, which only covers 29% of them, while the LEED System and the ATHENA™ Tool assess 86% of the phases of the life cycle. More specifically, Passivhaus focusses only on the phases of design and use of the building, while LEED ignores the phase of demolition, and ATHENA™ overlooks the phase of use (Table 5). However, the latter does accept data from simulations carried out with other instruments, and simplifies the calculations for obtaining an LCA of a building, compared to the other methods.

The inclusion of all phases in Level(s) means that the main agents responsible for a building adopt an cradle-to-grave approach to the life cycle, starting from the design phase (based on calculations, simulations and scenarios) and ending with the deconstruction of the building, and including the manufacture of products and materials used to construct the building, the construction of the building itself, the phase of use (measured according to the performance and satisfaction of occupants), and the reuse and recycling of materials. In addition, Level(s) is the only method to establish a link between the phases of the project and valuation-related aspects of the property, and provides information regarding the cost and economic benefit of each of the phases (Dodd et al., 2017b).

(ii) Sustainable aspects considered

With regard to sustainable aspects, Figure 9 shows that only Level(s) and LEED cover all sustainable aspects. The Passivhaus Standard and the ATHENA™ Tool address 33% of them, focussing only on the environmental aspect of sustainability (Table 5), and more specifically, energy consumption, high levels of thermal comfort and a catalogue of construction materials and systems that allow the above requirements to be met.

(iii) Assessment categories

In the case of categories, Level(s), again, is the only method to include all of them (Figure 9), followed by LEED, with 90% of categories assessed, whereas the Passivhaus Standard only considers 20% of the identified categories.

Specifically, as indicated in (Table 5), the Passivhaus Standard only takes into account categories (C4) Energy and (C5) Indoor Environmental Quality. In the case of ATHENA™, it can be observed that categories (C2) Water, (C3) Materials and Resources and (C4) Energy are once again the fundamental basis of this methodological group, facilitating the designer's choice of construction materials or systems that minimise the impact of the building on the environment. In the case of LEED, the concept of sustainability is more extensive than the two previous methods. Thus, although it only covers nine categories, it does include (C9) Circular Economy with the aim of optimising the use of resources, facilitating disassembly and the reuse (not recycling) of the materials, systems and subsystems that make up the building.

Finally, Level(s), as a more complete method is the only method to include category (C10) Adaptation to Climate Change. This is because one of the priority goals of the framework is to safeguard user health and wellbeing in estimated future climate conditions, taking into account an increased risk of extreme weather events, which may require consideration of the durability and strength of construction elements, or the increased risk of flooding, thereby considering the capacity of drainage systems and the strength of structures, among others (Dodd et al., 2017b).

(iv) Types of projects where assessment is applied

Unlike the other variables studied, Level(s) in this respect is the method with the least coverage (Table 5); while LEED v4, Passivhaus and ATHENA™ assess 80% of the type or status of projects, Level(s) only assesses 63%, focussing exclusively on new-builds and refurbishment in the residential and tertiary (offices) sectors.

3.5. Discussion

From the foregoing analysis, we can conclude that since the 1970s, various strategies have been developed with the aim of reducing the energy consumption of buildings (Feist, Schnieders, Dorer, & Haas, 2005) and reducing losses. However, the introduction of the first BREEAM system signalled an attempt to rethink the concept of a building as a whole. Since then, the field of methods has seen a rapid increase in the number of instruments introduced into the global market (Cole, 2006).

However, based on the results of the foregoing analysis, despite the number of existing methods, whose ultimate goal is to achieve a construction or building that is unquestionably sustainable, differences in the way the different methods (regardless of the group to which they belong) address the various variables (phases of the life cycle, sustainable aspects, categories and types and statuses of projects) show that each of these methods individually fails to consider the complete study of the sustainable building. This is due, among other factors, to the year of development, the concept of sustainability in the country or region of application (Cole, 2006), the type of regulatory body, the interests of the agents involved, the evolution of the concept of sustainability, and the need to adapt methods to the construction industry in the country of application.

An analysis of the different variables suggests that the identified methods generally cover all the phases in the life cycle of a building, even though they may take a different approach and focus on different sustainable aspects and their corresponding assessment categories, especially the environmental aspect, and more specifically energy efficiency and indoor environmental quality. We can also observe how the social and economic approaches are far less prevalent, due in part to the limited knowledge or vagueness of the concept of sustainability itself, to the greater difficulty in assessing aspects and categories related to social and economic approaches, and to the fact that the methods traditionally focus on purely environmental sustainability. However, in recent decades, and especially since the year 2000, there has been a shift towards social and economic approaches, partly because construction activities are a social process.

The results have shown that the vast majority of the methods included in this study can be used to assess the majority of buildings, type and status of construction projects. Moreover, if we take into account the development date of the various methods, we can observe a marked increase in the number of type or status of projects assessed by these methods after the year 2000. This could be due to the fact that after using the initial instruments, the main agents involved realised that they needed specific versions that could be used to address different types of projects or components.

Based on the comparison between the four identified methods, and bearing in mind that LEED v4, Passivhaus and ATHENA™ are considered representative methods of the group to which they correspond, Figure 10 shows the global scope of Groups I, II and III and Level(s).

Finally, Figure 10 shows the relationship between the three groups and Level(s), according to the scope of the different study variables, based on the results obtained. As shown in Figure 10, Group II (Standards) only assesses two phases of the life cycle and the environmental aspect of sustainability, but like Group III (Tools) does not cover all the related categories, although the latter does cover all phases of the life cycle. Group I (Systems), cover the whole life cycle and the three sustainability aspects, but does not cover all the categories. It can be observed that only Level(s) covers all phases of the life cycle, all the sustainability aspects, and all the sustainable building categories. Level(s) includes the other three groups, and is therefore the most complete assessment method to date.

4. Conclusions

Since the creation of the first tool for assessing building sustainability (TRYNNS, in 1975) up to the recent implementation of the European Level(s) framework, more than 600 methods have been developed. These have gradually been adapted to the sustainable building concept, and aimed at assessing the various aspects of sustainability. All of them have played a transcendental role in the development of sustainable buildings by raising awareness of the main agents involved in recent years, even though their objectives, areas of application and structures are very different, depending on the country and launch date, as well as the aspects of sustainability they set out to address.

In this study, 36 of the 101 identified methods have been analysed. These were selected based on the number of m^2 certified to date, endorsement from the country of application, and the level of update. This analysis has evidenced the major differences between the three groups into which the most used methods can be classified (Systems, Standards and Tools), as well as Level(s). A comparison between the methods included in each of these groups has also been performed to select those with the greatest scope.

In conclusion, energy and indoor environmental quality, related to environmental aspects, are present in all the methods studied, which proves that these are the most influential, easily accessed aspects of sustainability compared to more recent social and economic aspects. Systems, in particular, are generally the methods that, to a greater or lesser extent, cover all aspects of a sustainable building. Nevertheless, not all the Systems cover all types of projects, nor assessment categories. In the case of the phases of the life cycle, however, it is the group with the greatest scope. By contrast, Standards are based solely on the environmental aspect of sustainability, focussing on criteria related to energy and indoor environmental quality, without including the other aspects prevalent in the modern concept of sustainable building. Moreover, they are only applied in two of the seven phases of the life cycle, i.e. the design and the use of the building. Tools are considered a halfway point between Systems and Standards, as they take into account both environmental and economic aspects, although the latter have little influence. In this case, not all the phases of the life cycle are covered; coverage is greater than in Standards, but less than in Systems. The comparative analysis of the variables studied (aspects, phases of the life cycle, categories, and type of projects) and criteria led to the conclusion that the most representative methods of each group are the following: LEED, in the case of Systems; Passivhaus, in the case of Standards; and ATHENA™, in the case of Tools.

Finally, the Level(s) tool, like Systems, assesses all the aspects of sustainable building, but unlike Systems it covers all the phases of the life cycle, as well as all the categories, including buildings within the circular economy framework. Moreover, it has the added value of considering adaptation and resilience to climate change. However, Level(s), for now, does not cover all the types of identified projects, as it is an instrument in the development phase. Therefore, the conclusion is that Level(s), currently in the testing phase, is the most complete method identified in this study, being based on earlier methods and designed to foster the adaptation of buildings to future climate changes and to encompass a broader concept of sustainable building.

Finally, this study, because of the large number of methods included in this study and the in-depth analysis made, is of great value to the main agents involved in sustainable building, giving them a clearer picture of the current assessment framework and enabling them to select the method which best responds to their needs.

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References

Al-Jebouri, M. F. A., Saleh, M. S., Raman, S. N., Rahmat, R. A. A. B. O. K., & Shaaban, A. K. (2017a). Toward a national sustainable building assessment system in Oman: Assessment categories and their performance indicators. *Sustainable Cities and Society*, *31*, 122–135. https://doi.org/10.1016/j.scs.2017.02.014

Al-Jebouri, M. F. A., Saleh, M. S., Raman, S. N., Rahmat, R. A. A. B. O. K., & Shaaban, A. K. (2017b). Toward a national sustainable building assessment system in Oman: Assessment categories and their performance indicators. *Sustainable Cities and Society*, *31*, 122–135. https://doi.org/10.1016/j.scs.2017.02.014

Ali, H. H., & Al Nsairat, S. F. (2009). Developing a green building assessment tool for developing countries – Case of Jordan. *Building and Environment*, *44*(5), 1053–1064. https://doi.org/10.1016/j.buildenv.2008.07.015

Alliance HQE-GBC – Alliance des professionnels pour un cadre de vie durable. (n.d.). Retrieved February 6, 2019, from http://www.hqegbc.org/accueil/

ArgentinaGBC Construcciones Sustentables. (n.d.). Retrieved February 6, 2019, from https://www.argentinagbc.org.ar/

Asdrubali, F., Baldinelli, G., Bianchi, F., & Sambuco, S. (2015). A comparison between environmental sustainability rating systems LEED and ITACA for residential buildings. *Building and Environment*, *86*, 98–108. https://doi.org/10.1016/j.buildenv.2015.01.001

Awadh, O. (2017a). Sustainability and green building rating systems: LEED, BREEAM, GSAS and Estidama critical analysis. *Journal of Building Engineering*, *11*, 25–29. https://doi.org/10.1016/j.jobe.2017.03.010

Awadh, O. (2017b). Sustainability and green building rating systems: LEED, BREEAM, GSAS and Estidama critical analysis. *Journal of Building Engineering*, *11*, 25–29. https://doi.org/10.1016/J.JOBE.2017.03.010

Baek, C., Park, S.-H., Suzuki, M., & Lee, S.-H. (2013). Life cycle carbon dioxide assessment tool for buildings in the schematic design phase. *Energy & Buildings*, *61*, 275–287. https://doi.org/10.1016/j.enbuild.2013.01.025

BEAM Plus New Buildings | Introduction - The Hong Kong Green Building Council (HKGBC) 香港綠色建築議會. (n.d.). Retrieved February 6, 2019, from https://www.hkgbc.org.hk/eng/NB_Intro.aspx

Berardi, U. (2015). Sustainability assessments of buildings, communities, and cities. *Assessing and Measuring Environmental Impact and Sustainability*, 497–545. https://doi.org/10.1016/B978-0-12-799968-5.00015-4

Bernardi, E., Carlucci, S., Cornaro, C., & Bohne, R. (2017). An Analysis of the Most Adopted Rating Systems for Assessing the Environmental Impact of Buildings. *Sustainability*, *9*(7), 1226. https://doi.org/10.3390/su9071226

BOMA Canada. (n.d.). Retrieved February 6, 2019, from http://bomacanada.ca/

BREEAM: the world's leading sustainability assessment method for masterplanning projects, infrastructure and buildings - BREEAM. (n.d.). Retrieved February 6, 2019, from https://www.breeam.com/

Building & Construction Authority. (n.d.). Retrieved February 7, 2019, from https://www.bca.gov.sg/

Building for Environmental and Economic Sustainability (BEES) | WBDG - Whole Building Design Guide. (n.d.). Retrieved February 7, 2019, from https://www.wbdg.org/additional-resources/tools/bees

Built Green. (n.d.). Retrieved February 7, 2019, from https://www.builtgreen.net/

Carbon Calculator Tools, Software and Support. (n.d.). Retrieved February 7, 2019, from https://www.carbonfootprint.com/carbonsoftware.html

Carpio, M., Zamorano, M., & Costa, M. (2013). Impact of using biomass boilers on the energy rating and CO2 emissions of Iberian Peninsula residential buildings. *Energy and Buildings*, *66*, 732–744. https://doi.org/10.1016/j.enbuild.2013.07.079

CASBEE Certification System. (n.d.). Retrieved February 6, 2019, from http://www.ibec.or.jp/CASBEE/english/certificationE.htm

Champagne, C. L., & Aktas, C. B. (2016). Assessing the Resilience of LEED Certified Green Buildings. *Procedia Engineering*, *145*, 380–387. https://doi.org/10.1016/j.proeng.2016.04.095

Chandratilake, S. R., & Dias, W. P. S. (2015). Ratio based indicators and continuous score functions for better assessment of building sustainability. *Energy*, *83*, 137–143. https://doi.org/10.1016/j.energy.2015.02.007

Chile GBC. (n.d.). Retrieved February 6, 2019, from http://www.chilegbc.cl/

Code for Sustainable Homes: Technical Guide. November 2010. (2010).

Código de Edificación de Vivienda (CEV) | Commission for Environmental Cooperation. (n.d.). Retrieved February 7, 2019, from http://www.cec.org/resources/código-de-edificación-de-vivienda-cev

Cole, R. J. (2006). Shared markets: coexisting building environmental assessment methods. *Building Research & Information*, *34*(4), 357–371. https://doi.org/10.1080/09613210600724624

Darko, A., Chan, A. P. C., Ameyaw, E. E., He, B.-J., & Olanipekun, A. O. (2017). Examining issues influencing green building technologies adoption: The United States green building experts' perspectives. *Energy and Buildings*, *144*, 320–332. https://doi.org/10.1016/j.enbuild.2017.03.060

DesignBuilder Software Ltd - Home. (n.d.). Retrieved February 7, 2019, from https://designbuilder.co.uk//

DGNB pre-certified and certified projects. (n.d.). Retrieved February 4, 2019, from https://www.dgnb-system.de/en/projects/

Ding, G. K. C. (2008). Sustainable construction—The role of environmental assessment tools. *Journal of Environmental Management*, *86*(3), 451–464. https://doi.org/10.1016/J.JENVMAN.2006.12.025

Dixit, M. K., Culp, C. H., & Fernández-Solís, J. L. (2013). System boundary for embodied energy in buildings: A conceptual model for definition. *Renewable and Sustainable Energy Reviews*, *21*, 153–164. https://doi.org/10.1016/j.rser.2012.12.037

Doan, D. T., Ghaffarianhoseini, A., Naismith, N., Zhang, T., Ghaffarianhoseini, A., & Tookey, J. (2017). A critical comparison of green building rating systems. *Building and Environment*, *123*, 243–260. https://doi.org/10.1016/j.buildenv.2017.07.007

Dodd, N., Cordella, M., Traverso, M., & Donatello, S. (2017a). Level(s)-A common EU framework of core sustainability indicators for office and residential buildings Part 3: How to make performance assessments using Level(s) (Beta v1.0). https://doi.org/10.2760/95143

Dodd, N., Cordella, M., Traverso, M., & Donatello, S. (2017b). Level(s)-A common EU framework of core sustainability indicators for office and residential buildings Parts 1 and 2: Introduction to Level(s) and how it works (Beta v1.0).

https://doi.org/10.2760/827838
Dong, Y. H., & Ng, S. T. (2015). A life cycle assessment model for evaluating the environmental impacts of building construction in Hong Kong. *Building and Environment*, *89*, 183–191. https://doi.org/10.1016/j.buildenv.2015.02.020
Eco-Bat 4.0. (n.d.). Retrieved February 7, 2019, from http://www.eco-bat.ch/index.php?option=com_content&view=article&id=64&Itemid=61&lang=en
Egyptian Green Building Council. (n.d.). Retrieved February 7, 2019, from http://egypt-gbc.org/ratings.html
EnergyPlus. (n.d.). Retrieved February 7, 2019, from https://energyplus.net/
Feist, W., Schnieders, J., Dorer, V., & Haas, A. (2005). Re-inventing air heating: Convenient and comfortable within the frame of the Passive House concept. *Energy and Buildings*, *37*(11), 1186–1203. https://doi.org/10.1016/j.enbuild.2005.06.020
GBC Brasil | Construindo um Futuro Sustentável |. (n.d.). Retrieved February 6, 2019, from http://www.gbcbrasil.org.br/
GBCe | Green building council españa. (n.d.). Retrieved February 4, 2019, from https://gbce.es/
GBCI México | GBCI. (n.d.). Retrieved February 8, 2019, from http://www.gbci.org/es/mexico
GEMIS - IINAS. (n.d.). Retrieved February 7, 2019, from http://iinas.org/gemis.html
Giannetti, B. F., Demétrio, J. C. C., Agostinho, F., Almeida, C. M. V. B., & Liu, G. (2018). Towards more sustainable social housing projects: Recognizing the importance of using local resources. *Building and Environment*, *127*, 187–203. https://doi.org/10.1016/j.buildenv.2017.10.033
Green Building Index. (n.d.). Retrieved February 6, 2019, from http://new.greenbuildingindex.org/
Green Building Initiative : Green Globes Certification. (n.d.). Retrieved February 6, 2019, from https://www.thegbi.org/green-globes-certification/
Green Star Tools – GBCSA. (n.d.). Retrieved February 6, 2019, from https://gbcsa.org.za/certify/green-star-sa/
GSAS Trust | GSAS: Global Sustainability Assessment System | GORD. (n.d.). Retrieved February 6, 2019, from http://www.gord.qa/gsas-trust
Haapio, A. (2012). Towards sustainable urban communities. *Environmental Impact Assessment Review*, *32*(1), 165–169. https://doi.org/10.1016/j.eiar.2011.08.002
Haapio, A., & Viitaniemi, P. (2008a). A critical review of building environmental assessment tools. *Environmental Impact Assessment Review*, *28*(7), 469–482. https://doi.org/10.1016/J.EIAR.2008.01.002
Haapio, A., & Viitaniemi, P. (2008b). A critical review of building environmental assessment tools. *Environmental Impact Assessment Review*, *28*(7), 469–482. https://doi.org/10.1016/J.EIAR.2008.01.002
Herramienta unificada LIDER-CALENER (HULC). (n.d.). Retrieved February 6, 2019, from https://www.codigotecnico.org/index.php/menu-recursos/menu-aplicaciones/282-herramienta-unificada-lider-calener
Home - MINERGIE Schweiz. (n.d.). Retrieved February 6, 2019, from https://www.minergie.ch/
Home | Green Rating for Integrated Habitat Assesment. (n.d.). Retrieved February 6, 2019, from http://www.grihaindia.org/
Hui, S. C. M. (2015). *Critical Evaluation of Zero Carbon Buildings in High Density Urban Cities*. *Zero Carbon Building Journal* (Vol. 3).
IE for Buildings | Athena Sustainable Materials Institute. (n.d.). Retrieved February 7, 2019, from http://www.athenasmi.org/our-software-data/impact-estimator/
IHOBE Sociedad Pública de Gestión Ambiental. (2010). Green Building Rating Systems: ¿Cómo evaluar la sostenibilidad en la edificación? *Ihobe*, (1ª Edición), 72. https://doi.org/10.1007/s13398-014-0173-7.2
Illankoon, I. M. C. S., Tam, V. W. Y., Le, K. N., & Shen, L. (2017). Key credit criteria among international green building rating tools. *Journal of Cleaner Production*, *164*,

209–220. https://doi.org/10.1016/j.jclepro.2017.06.206
International WELL Building Institute |. (n.d.). Retrieved February 7, 2019, from https://www.wellcertified.com/
Itaca. (n.d.). Retrieved February 6, 2019, from http://itaca.org/valutazione_sostenibilita.asp
Kamaruzzaman, S. N., Lou, E. C. W., Zainon, N., Mohamed Zaid, N. S., & Wong, P. F. (2016). Environmental assessment schemes for non-domestic building refurbishment in the Malaysian context. *Ecological Indicators*, *69*, 548–558. https://doi.org/10.1016/j.ecolind.2016.04.031
Kofoworola, O. F., & Gheewala, S. H. (2008). Environmental life cycle assessment of a commercial office building in Thailand. *The International Journal of Life Cycle Assessment*, *13*(6), 498–511. https://doi.org/10.1007/s11367-008-0012-1
Kumanayake, R., & Luo, H. (2018). A tool for assessing life cycle CO2 emissions of buildings in Sri Lanka. *Building and Environment*, *128*, 272–286. https://doi.org/10.1016/J.BUILDENV.2017.11.042
LCA-Center, AIST -Research Activities: Software AIST-LCA Ver.4. (n.d.). Retrieved February 8, 2019, from https://www.aist-riss.jp/old/lca/cie/activity/software/aist/outline.html
LCA In Sustainable Architecture. (n.d.). Retrieved February 7, 2019, from https://sustainableresourcedatabase.weebly.com/lca-in-sustainable-architecture.html
LEB Technical reference | Low Energy Buildings. (n.d.). Retrieved February 7, 2019, from http://www.lowenergybuildings.org.uk/leb/technical-information/
Lee, K., Tae, S., & Shin, S. (2009). Development of a Life Cycle Assessment Program for building (SUSB-LCA) in South Korea. *Renewable and Sustainable Energy Reviews*, *13*(8), 1994–2002. https://doi.org/10.1016/J.RSER.2009.01.002
LEED | USGBC. (n.d.). Retrieved February 4, 2019, from https://new.usgbc.org/leed
LEED India :: Green Building Information Gateway. (n.d.). Retrieved February 6, 2019, from http://www.gbig.org/collections/14555
LiderA – Sistema de avaliação da sustentabilidade. (n.d.). Retrieved February 4, 2019, from http://www.lidera.info/?p=MenuPage&MenuId=19
Life Cycle Assessment software- Umberto LCA+ Software. (n.d.). Retrieved February 7, 2019, from https://www.ifu.com/en/umberto/lca-software/
Lu, Y., Geng, Y., Liu, Z., Cote, R., & Yu, X. (2017). Measuring sustainability at the community level: An overview of China's indicator system on National Demonstration Sustainable Communities. *Journal of Cleaner Production*, *143*, 326–335. https://doi.org/10.1016/j.jclepro.2016.12.105
Macías, M., & García Navarro, J. (2010). Metodología y herramienta VERDE para la evaluación de la sostenibilidad en edificios. *Informes de La Construcción*, *62*(517), 87–100. https://doi.org/10.3989/ic.08.056
Mattoni, B., Guattari, C., Evangelisti, L., Bisegna, F., Gori, P., & Asdrubali, F. (2018). Critical review and methodological approach to evaluate the differences among international green building rating tools. *Renewable and Sustainable Energy Reviews*, *82*, 950–960. https://doi.org/10.1016/j.rser.2017.09.105
Miller, D., Doh, J.-H., Panuwatwanich, K., & van Oers, N. (2015). The contribution of structural design to green building rating systems: An industry perspective and comparison of life cycle energy considerations. *Sustainable Cities and Society*, *16*, 39–48. https://doi.org/10.1016/j.scs.2015.02.003
Monterotti, C. (2013). Análisis y propuesta sobre la contribución de las herramientas de evaluación de la sostenibilidad de los edificios a su eficiencia ambiental. *TDX (Tesis Doctorals En Xarxa)*. Retrieved from https://upcommons.upc.edu/handle/2117/94858#.XFgW2ya-diA.mendeley
MyCrest. (n.d.). Retrieved February 6, 2019, from http://www.cidb.gov.my/index.php/en/bidang-utama/pembinaan-mampan/mycrest
NABERS. (n.d.). Retrieved February 6, 2019, from https://www.nabers.gov.au/

New Zealand Green Building Council. (n.d.). Retrieved February 6, 2019, from https://www.nzgbc.org.nz/GreenStar
Nordic Ecolabel | Nordic Ecolabel. (n.d.). Retrieved February 6, 2019, from https://www.nordic-ecolabel.org/
NZEB. (n.d.). Retrieved February 7, 2019, from http://www.nzeb.in/
Økoprofil | NAL. (n.d.). Retrieved February 6, 2019, from https://www.arkitektur.no/?nid=155686&pid0=155001
openLCA. (n.d.). Retrieved February 7, 2019, from http://www.openlca.org/
Passivhaus Institut. (n.d.). Retrieved February 7, 2019, from https://passiv.de/en/02_informations/02_passive-house-requirements/02_passive-house-requirements.htm
Petrovic-Lazarevic, S. (2008). The development of corporate social responsibility in the Australian construction industry. *Construction Management and Economics*, *26*(2), 93–101. https://doi.org/10.1080/01446190701819079
Roh, S., Tae, S., & Shin, S. (2014). Development of building materials embodied greenhouse gases assessment criteria and system (BEGAS) in the newly revised Korea Green Building Certification System (G-SEED). *Renewable and Sustainable Energy Reviews*, *35*, 410–421. https://doi.org/10.1016/J.RSER.2014.04.034
Saldaña-Márquez, H., Gómez-Soberón, J. M., Arredondo-Rea, S. P., Gámez-García, D. C., & Corral-Higuera, R. (2018). Sustainable social housing: The comparison of the Mexican funding program for housing solutions and building sustainability rating systems. *Building and Environment*, *133*, 103–122. https://doi.org/10.1016/J.BUILDENV.2018.02.017
Sandanayake, M., Zhang, G., & Setunge, S. (2018). A comparative method of air emission impact assessment for building construction activities. *Environmental Impact Assessment Review*, *68*, 1–9. https://doi.org/10.1016/j.eiar.2017.09.003
SBTool | International Initiative for a Sustainable Built Environment. (n.d.). Retrieved February 6, 2019, from http://www.iisbe.org/sbmethod
SBToolCZ. (n.d.). Retrieved February 6, 2019, from https://www.sbtool.cz/en/
Seinre, E., Kurnitski, J., & Voll, H. (2014). Building sustainability objective assessment in Estonian context and a comparative evaluation with LEED and BREEAM. *Building and Environment*, *82*, 110–120. https://doi.org/10.1016/j.buildenv.2014.08.005
SimaPro | The World's Leading LCA Software. (n.d.). Retrieved February 7, 2019, from https://simapro.com/
Sustainable Building - VTT Materials and Construction. (n.d.). Retrieved February 6, 2019, from http://virtual.vtt.fi/virtual/proj6/environ/ympluok_e.html
Sustainable Building Assessment Tool: The Sustainable Building Assessment Tool. (n.d.). Retrieved February 6, 2019, from http://www.sustainablebuildingassessmenttool.com/p/the-sustainabilit.html
Sweden Green Building Council. (n.d.). Retrieved February 7, 2019, from https://www.sgbc.se/
TRNSYS : Transient System Simulation Tool. (n.d.). Retrieved February 7, 2019, from http://www.trnsys.com/
Vega Clemente, R. (2015). Evaluación de la sostenibilidad de sistemas de construcción industrializados de fachada en edificios de vivienda colectiva. Retrieved from http://oa.upm.es/38121/#.XFgdO0Z4WCU.mendeley
VGBC | Vietnam Green Building Council. (n.d.). Retrieved February 7, 2019, from https://vgbc.vn/en/
Vyas, G. S., & Jha, K. N. (2018). What does it cost to convert a non-rated building into a green building? *Sustainable Cities and Society*, *36*, 107–115. https://doi.org/10.1016/J.SCS.2017.09.023
What's National Green Building Standard (NGBS). (n.d.). Retrieved February 7, 2019, from http://ngbs.com/the-ngbs-green-promise
Why Green Star? | Green Building Council of Australia. (n.d.). Retrieved February 6,

2019, from https://new.gbca.org.au/green-star/
Yang, L., He, B.-J., & Ye, M. (2014). Application research of ECOTECT in residential estate planning. *Energy and Buildings*, *72*, 195–202. https://doi.org/10.1016/J.ENBUILD.2013.12.040
Ye, L., Cheng, Z., Wang, Q., Lin, W., & Ren, F. (2013). Overview on Green Building Label in China. *Renewable Energy*, *53*, 220–229. https://doi.org/10.1016/J.RENENE.2012.11.022
Yılmaz, M., & Bakış, A. (2015). Sustainability in Construction Sector. *Procedia - Social and Behavioral Sciences*, *195*, 2253–2262. https://doi.org/10.1016/J.SBSPRO.2015.06.312
Yu, W., Li, B., Yang, X., & Wang, Q. (2015). A development of a rating method and weighting system for green store buildings in China. *Renewable Energy*, *73*, 123–129. https://doi.org/10.1016/j.renene.2014.06.013
Zhang, Y., Wang, J., Hu, F., & Wang, Y. (2017). Comparison of evaluation standards for green building in China, Britain, United States. *Renewable and Sustainable Energy Reviews*, *68*, 262–271. https://doi.org/10.1016/j.rser.2016.09.139
Zuo, J., Jin, X.-H., & Flynn, L. (2012). Social Sustainability in Construction – An Explorative Study. *International Journal of Construction Management*, *12*(2), 51–63. https://doi.org/10.1080/15623599.2012.10773190
환경부, 국토교통부 녹색건축인증 지원시스템. (n.d.). Retrieved February 7, 2019, from http://gseed.greentogether.go.kr/sys/gms/selectGreenMain.do
主頁 - 屋宇署. (n.d.). Retrieved February 6, 2019, from https://www.bd.gov.hk/english/documents/index_CEPAS.html
綠建築標章Q&A Green Building Label Questions and Answer. (n.d.). Retrieved February 6, 2019, from http://twgbqanda.com/english/e_tgbr.php?Type=2&menu=e_tgbr_class&pic_dir_list=0

Figure 1. Method

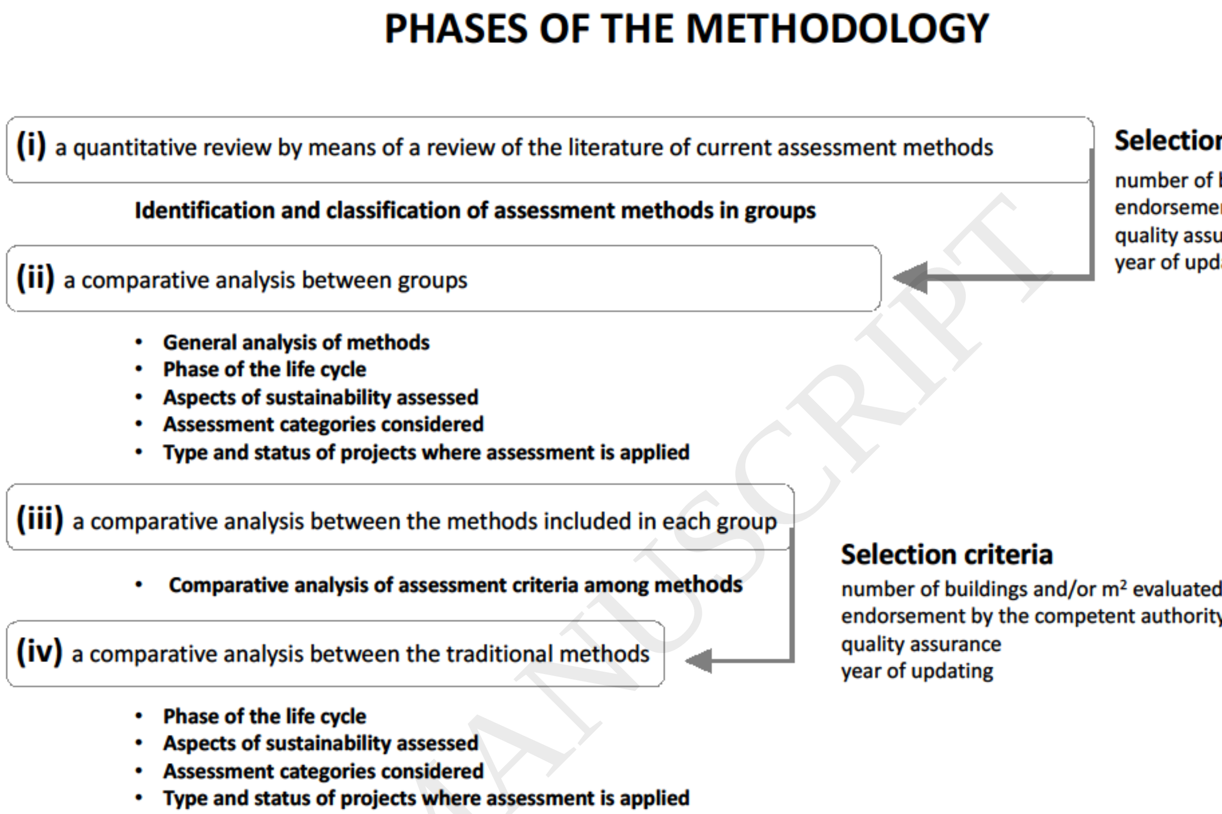

Figure 2. Overview of the Level(s) framework

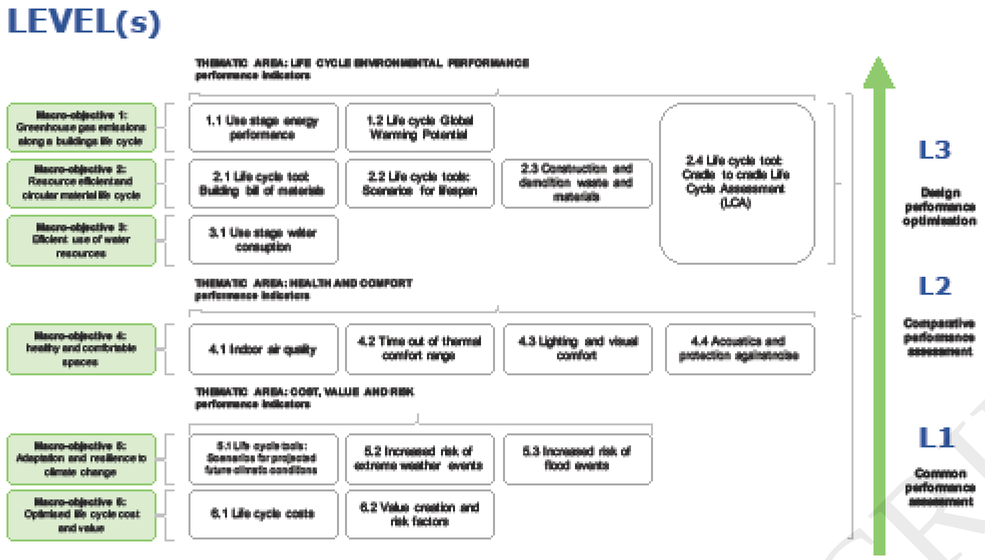

Figure 3. Classification of building sustainability assessment methods

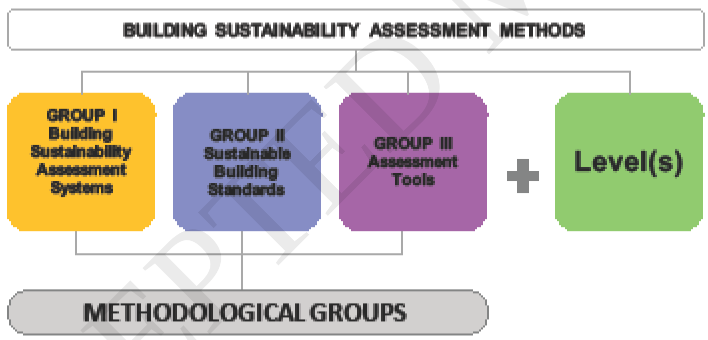

Figure 4. Evolution of the number of sustainable building assessment methods

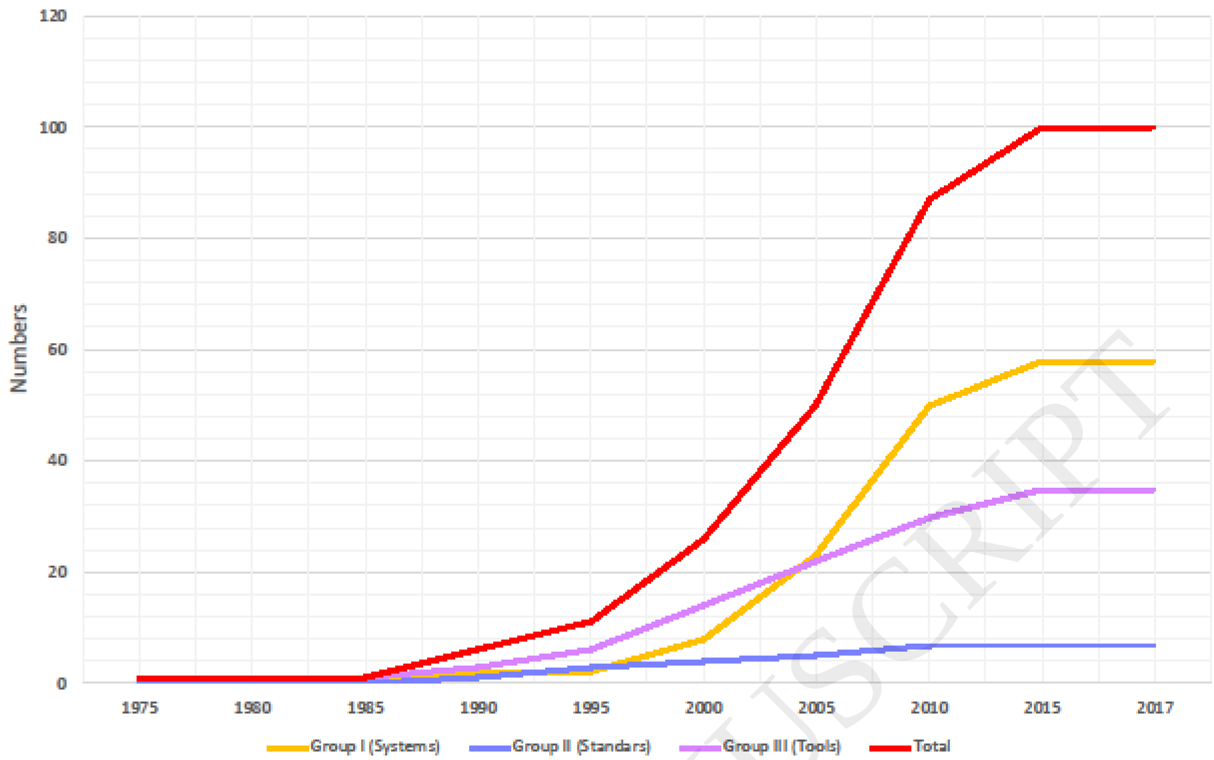

Figure 5. Area of application of the methods

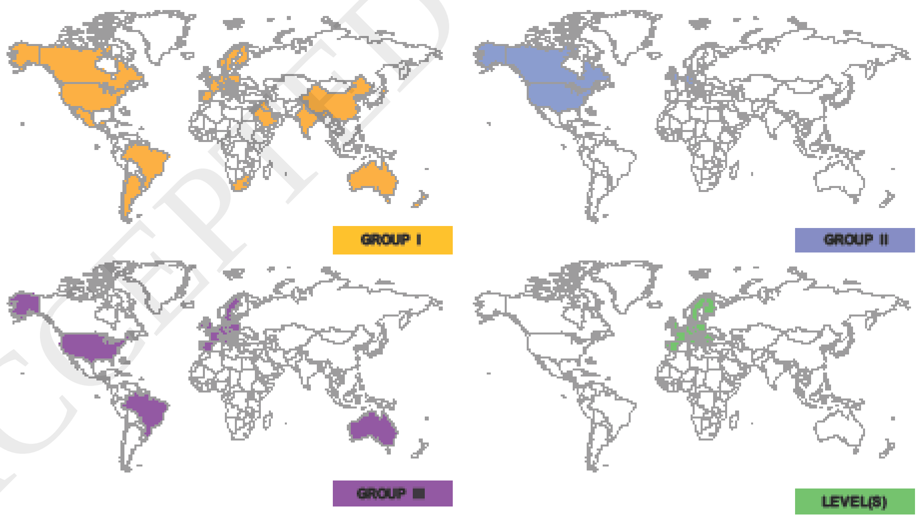

Figure 6.Percentage of methods per group, which include the phases of the life cycle (a), the three aspects of sustainability (b), assessment categories (c) and types and statuses of projects (d)

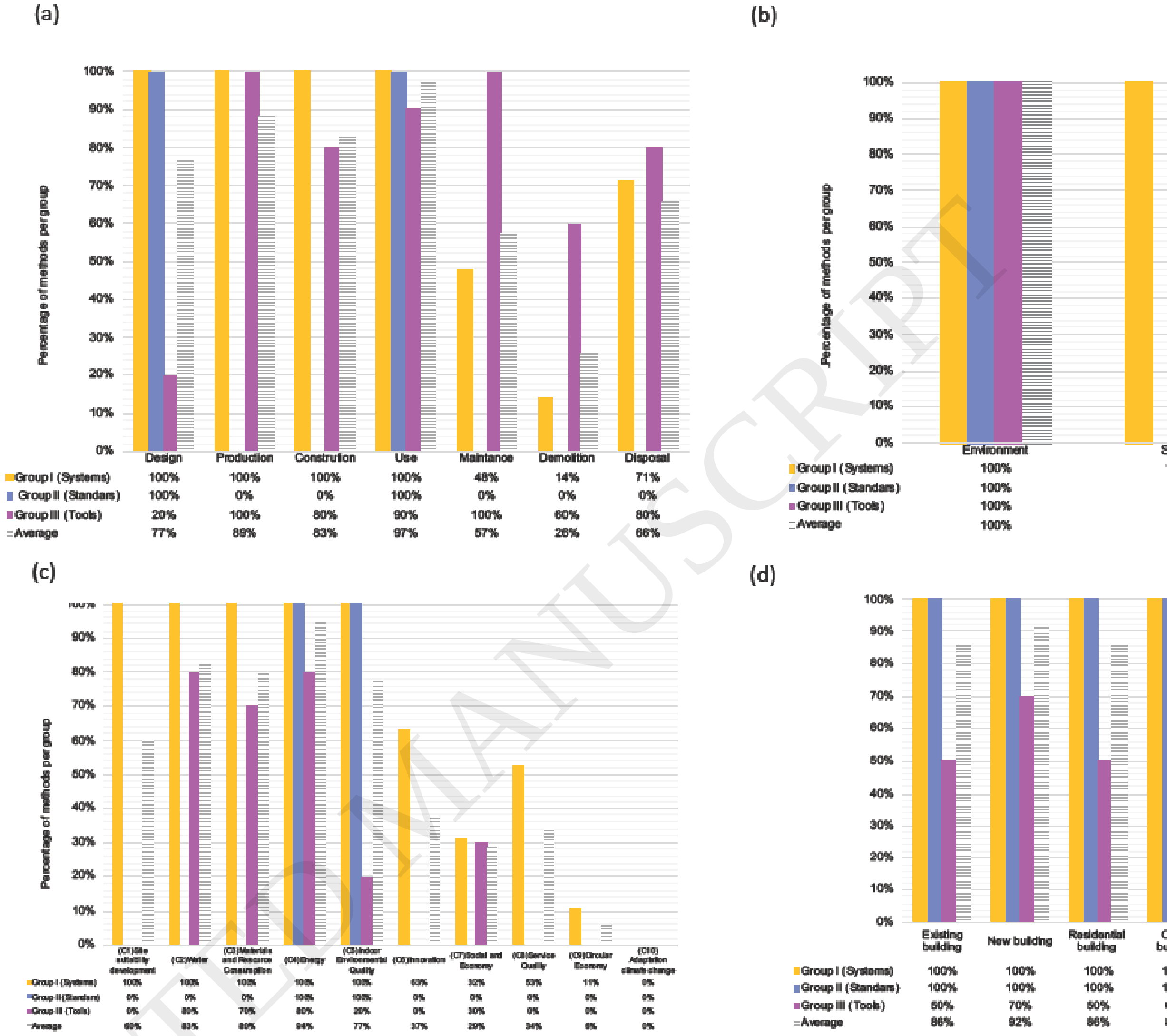

Figure 7. Percentage of criteria achieved by the methods

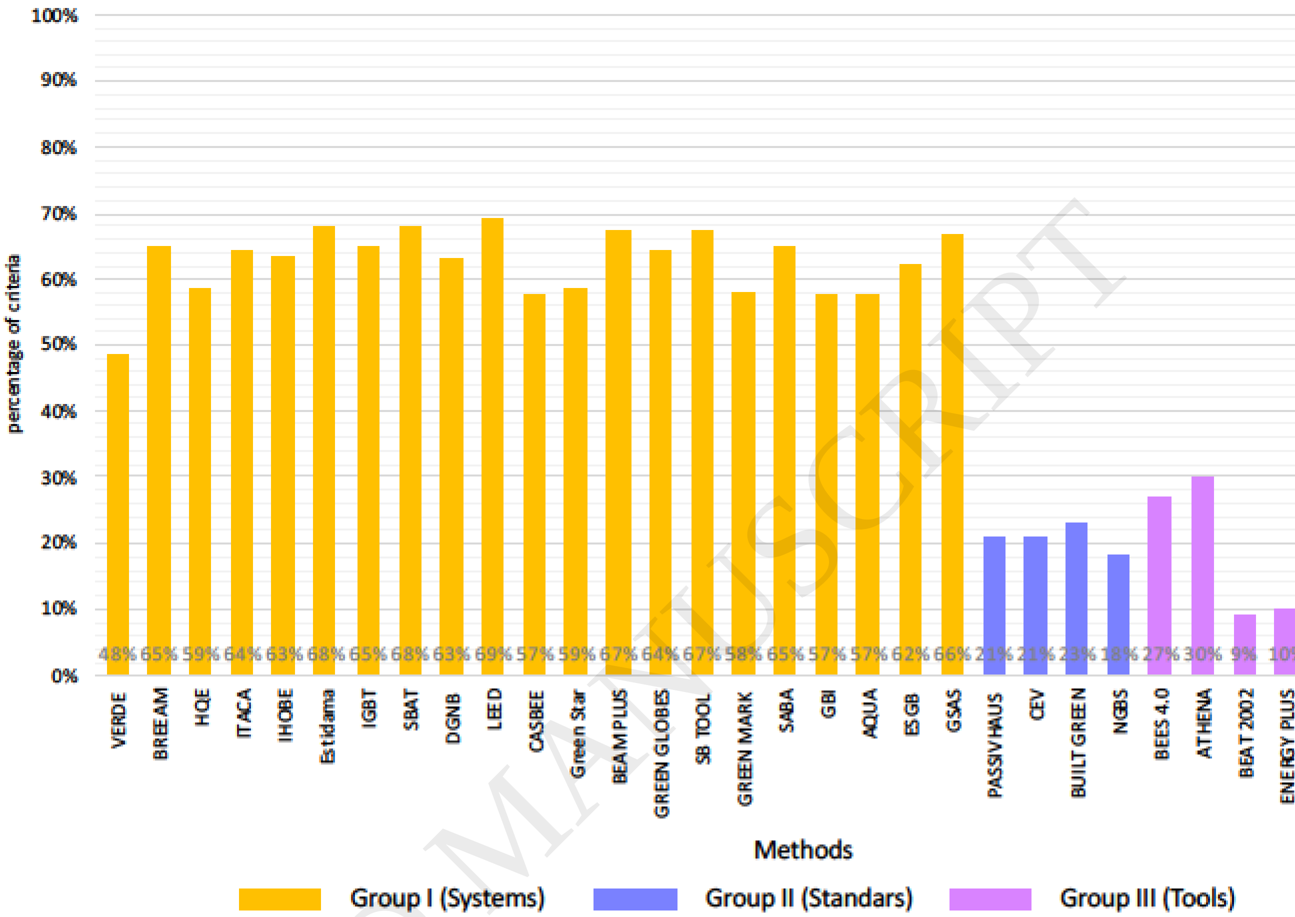

Figure 8. Percentage of criteria per Categories

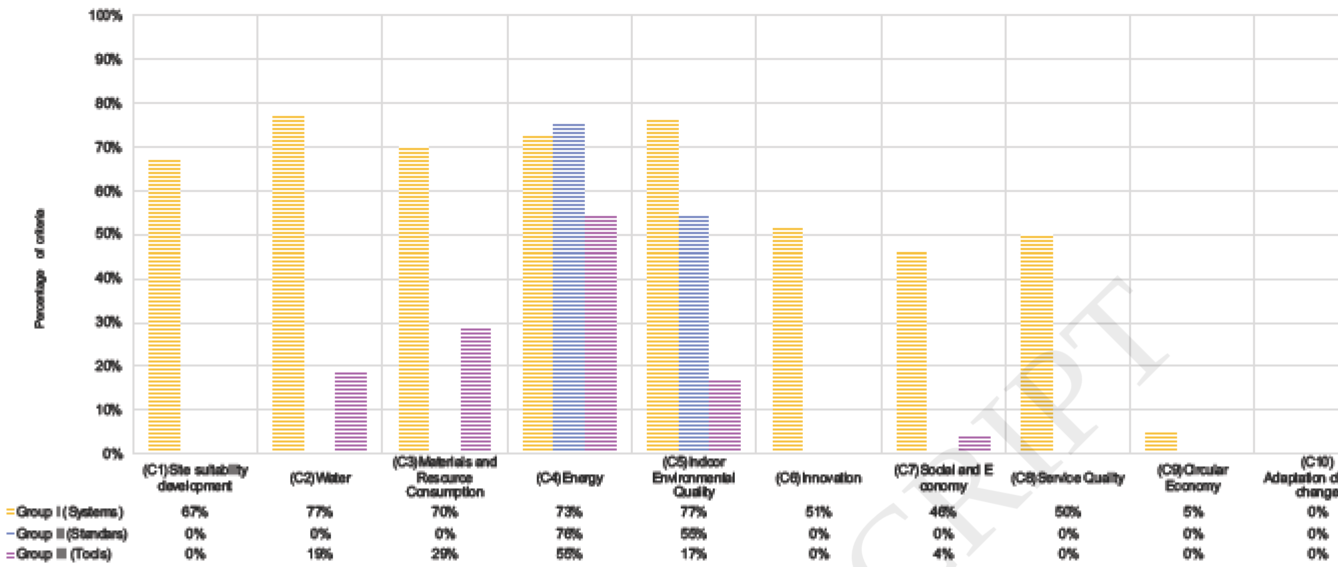

Figure 9. Percentage of the scope of each method according to the variables identified

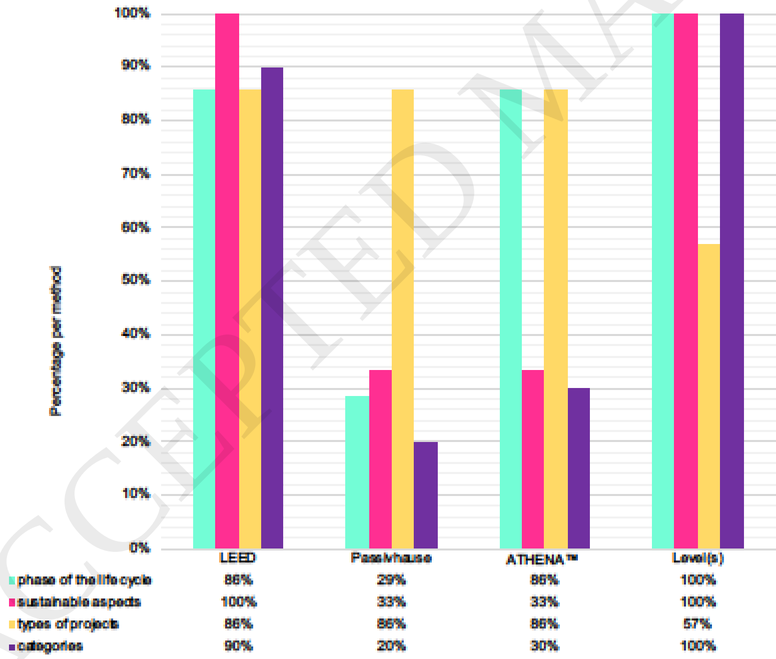

Figure 10. Relationships between Groups I,II,III and Level(s)

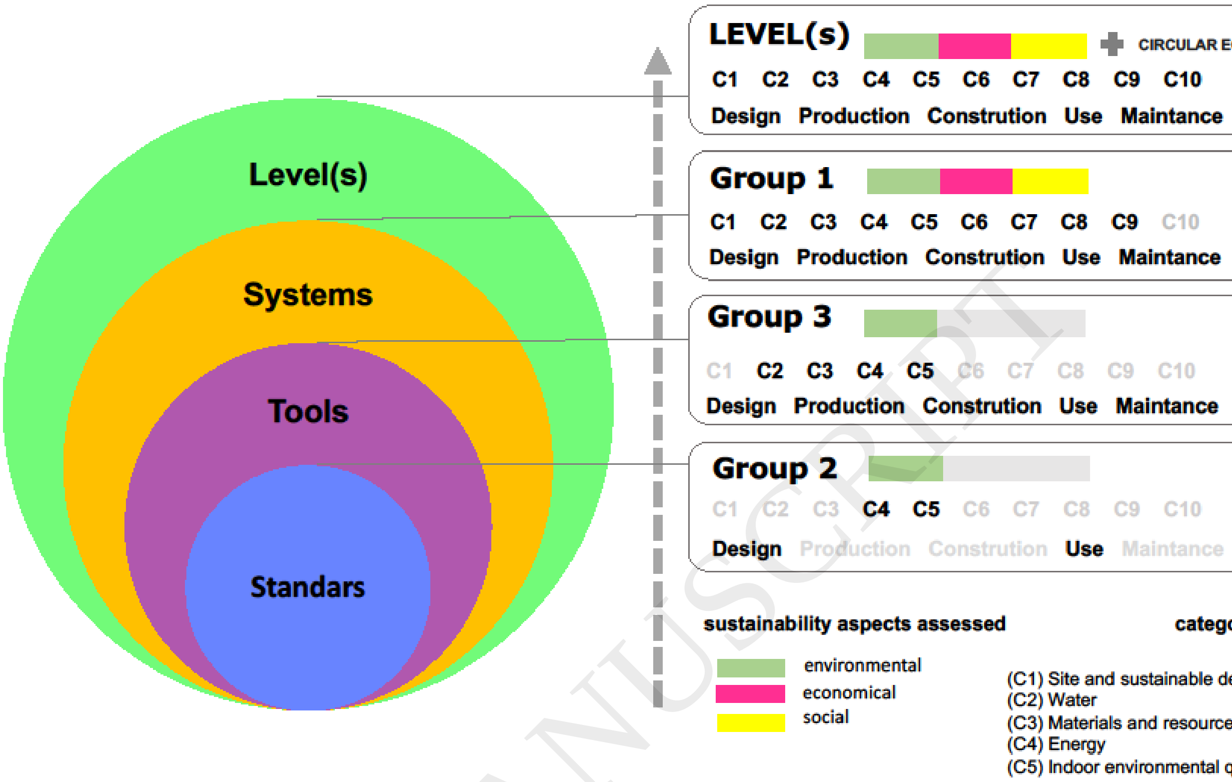
Level(s)
Systems
Tools
Standars
LEVEL(s)
CIRCULAR E
C1 C2 C3 C4 C5 C6 C7 C8 C9 C10
Design Production Constrution Use Maintance
Group 1
C1 C2 C3 C4 C5 C6 C7 C8 C9 C10
Design Production Constrution Use Maintance
Group 3
C1 C2 C3 C4 C5 C6 C7 C8 C9 C10
Design Production Constrution Use Maintance
Group 2
C1 C2 C3 C4 C5 C6 C7 C8 C9 C10
Design Production Constrution Use Maintance
sustainability aspects assessed
environmental
economical
social
categ
(C1) Site and sustainable de
(C2) Water
(C3) Materials and resource
(C4) Energy
(C5) Indoor environmental q

Table 1. Categories of assessment considered

Categories	study areas
(C1)Site and sustainable development	impacts related to the planning, design, regeneration and influence of the characteristics of the site; transport management and external light pollution.
(C2)Water	performance, cycle, use and monitoring of the various water sources
(C3)Materials and resource consumption	use, recycling, reuse and environmental impact of materials and resources
(C4)Energy	reduction, control, consumption and use of energy
(C5)Indoor environmental quality	environmental ergonomics (reduction and elimination of pollutants, hygrothermal and acoustic comfort, and light quality)
(C6)Innovation	designs, processes and strategies that promote sustainability in the built environment and building
(C7)Social and economy	use of traditional local materials and techniques, design compatible with cultural values, the cost of use and commercial viability
(C8)Service Quality	efficiency in the use of the spaces, the capacity of local control of the different systems, and the efficiency of an adequate management and maintenance plan
(C9)Circular Economy	use of resources and reuse of building materials, systems and subsystems
(C10)Adaptation climate change	ability of buildings to adapt to climate change and its consequences without incurring damage

Table 2. Catalogue of methods identificated in this study

Country	Method	Name	Year first published	Responsible Organisation	Buildings certified	Ref.
			GROUP I: SYSTEMS			
Spain	VERDE	VERDE	2006	Green Building Council España (GBCe)	82	(“GBCe | Green building council españa,” n.d.)
	Guías de edificación sostenible	Guías de edificación sostenible del País Vasco	2005	IHOBE	N/A	(IHOBE Sociedad Pública de Gestión Ambiental, 2010)
	DGNB System	Deutsche Gesellschaft für Nachhaltiges Bauen	2011	AEIC (Associació d'Enginyers Industrials de Catalunya	4	(“DGNB pre-certified and certified projects,” n.d.)
	BREEAM® ES	Building Research Establishment Environmental Assessment Methodology	2009	Technological Institute of Galicia Foundation (ITG); BRE Global Ltd. (BRE)	375	(“BREEAM: the world's leading sustainability assessment method for masterplanning projects, infrastructure and buildings - BREEAM,” n.d.)
Portugal	Lider A	Leading the Environment for sustainable construction	2005	Instituto Superior Técnico, Lisbon	24	(“LiderA – Sistema de avaliação da sustentabilidade,” n.d.)
	SBTool PT	Sustainable Building Tool	2007	iiSBE Portugal, LFTC-UM, ECOCHOICE	N/A	(“SBTool | International Initiative for a Sustainable Built Environment,” n.d.)
Germany	DGNB System	Deutsche Gesellschaft für Nachhaltiges Bauen	2007	German Sustainable Building Council (DGNB)	1073	(“DGNB pre-certified and certified projects,” n.d.)
	BREEAM® DE	Building Research Establishment Environmental Assessment Methodology	2011	TÜV SÜD Industrie Service GmbH (DIFNI) Building Research Establishment (BRE)	245	(“BREEAM: the world's leading sustainability assessment method for masterplanning projects, infrastructure and buildings - BREEAM,” n.d.)
United Kingdom	BREEAM®	Building Research Establishment Environmental Assessment Methodology	1990	Building Research Establishment (BRE)	563,731	(“BREEAM: the world's leading sustainability assessment method for masterplanning projects, infrastructure and buildings - BREEAM,” n.d.)
	CSH	Code for Sustainable Home	2007	Building Research Establishment (BRE) and the Construction Industry Research and Information Association (CIRIA)	N/A	(“Code for Sustainable Homes: Technical Guide. November 2010,” 2010)
Austria	DGNB System	Deutsche Gesellschaft für Nachhaltiges Bauen	2009	Österreichische Gesellschaft für Nachhaltige Immobilienwirtschaft (ÖGNI)	56	(“DGNB pre-certified and certified projects,” n.d.)
	BREEAM® AT	Building Research Establishment Environmental Assessment Methodology	2010	TÜV SÜD Industrie Service GmbH (DIFNI) Building Research Establishment (BRE)	44	(“BREEAM: the world's leading sustainability assessment method for masterplanning projects, infrastructure and buildings - BREEAM,” n.d.)
Luxembourg	BREEAM® LU	Building Research Establishment Environmental Assessment Methodology	2009	TÜV SÜD Industrie Service GmbH (DIFNI) Building Research Establishment (BRE)	97	(“BREEAM: the world's leading sustainability assessment method for masterplanning projects, infrastructure and buildings - BREEAM,” n.d.)

Switzerland	BREEAM® CH	Building Research Establishment Environmental Assessment Methodology	2010	TÜV SÜD Industrie Service GmbH (DIFNI) Building Research Establishment (BRE)	132	(“BREEAM: the world’s leading sustainability assessment method for masterplanning projects, infrastructure and buildings - BREEAM,” n.d.)
	MINERGIE®	The MINERGIE® - Standard for Buildings	1998	Minergie Building Agency	46,047	(“Home - MINERGIE Schweiz,” n.d.)
	DGNB System	Deutsche Gesellschaft für Nachhaltiges Bauen	2010	Swiss Sustainable Building Council (SGNI)	3	(“DGNB pre-certified and certified projects,” n.d.)
Hungary	DGNB System	Deutsche Gesellschaft für Nachhaltiges Bauen	2010	TÜV SÜD Industrie Service GmbH (DIFNI)	3	(“DGNB pre-certified and certified projects,” n.d.)
France	HQE™Method	Haute Qualité Environnementale	1996	Association pour la Haute Qualité Environnementale	380,000	(“Alliance HQE-GBC – Alliance des professionnels pour un cadre de vie durable,” n.d.)
Italy	Protocollo ITACA	Protocollo ITACA	2004	Istituto per l’Innovazione eTrasparenza degli Appalti e la Compatibilita Ambientale (ITACA)	N/A	(“Itaca,” n.d.)
Czech Republic	SBTool CZ	Sustainable Building Tool	2010	iiSBE International, CIDEAS	20	(“SBToolCZ,” n.d.)
Finland	PromisE	PromisE	2004	Technical Research Centre of Finland (VTT)	N/A	(“Sustainable Building - VTT Materials and Construction,” n.d.)
Norway	Økoprofil	Ecoprofil	2004	Byggforsk - Norwegian Building Research Institute	N/A	(“Økoprofil | NAL,” n.d.)
Nordic Countries	Nordic Swan Ecolabel	Nordic Swan Ecolabel	1989	Nordic Council of Ministers	28	(“Nordic Ecolabel | Nordic Ecolabel,” n.d.)
Denmark	DGNB System	Deutsche Gesellschaft für Nachhaltiges Bauen	2012	Green Building Council Denmark	45	(“DGNB pre-certified and certified projects,” n.d.)
United States of America	LEED®	Leadership in Energy and Environmental Design	2000	United States Green Building Council (USGBC)	92,000	(“LEED | USGBC,” n.d.)
	GREEN GLOBES	Green Globes	2004	The Green Building Initiative (GBI)	1,352	(“Green Building Initiative : Green Globes Certification,” n.d.)
Canada	GREEN GLOBES	Green Globes	2000	The Green Building Initiative (GBI)	149	(“Green Building Initiative : Green Globes Certification,” n.d.)
	BOMA BEST	Building Environmental Standards	2005	BOMA Canada	2,227	(“BOMA Canada,” n.d.)
Mexico	LEED® MEXICO	Leadership in Energy and Environmental Design	2008	Mexico GBC	N/A	(“GBCI México | GBCI,” n.d.)
Chile	CES®	Sustainable Building Certification	2014	Chile Green Building Council (Chile GBC)	13	(“Chile GBC,” n.d.)
	LEED® Chile	Leadership in Energy and Environmental Design	2010	Chile Green Building Council (Chile GBC)	321	(“Chile GBC,” n.d.)
Argentina	LEED® Argentina	Leadership in Energy and Environmental Design	2007	Argentina Green Building Council (AGBC)	112	(“ArgentinaGBC Construcciones Sustentables,” n.d.)
Brazil	LEED® Brazil	Leadership in Energy and Environmental Design	2007	Bazil Green Building Council (Brazil GBC)	714	(“GBC Brasil | Construindo um Futuro Sustentável |,” n.d.)

Brazil	AQUA-HQE	Haute Qualité Environnementale	2008	Fundação Vanzolini	N/A	(Saldaña-Márquez, Gómez-Soberón, Arredondo-Rea, Gámez-García, & Corral-Higuera, 2018)
South Africa	GREEN STAR SA	Green Star South Africa	2008	Green Building Council SA (GBCSA)	313	(“Green Star Tools – GBCSA,” n.d.)
	SBAT	South African Sustainable Building Assessment Tool	2002	Council for Scientific and Industrial Research (CSIR)	N/A	(“Sustainable Building Assessment Tool: The Sustainable Building Assessment Tool,” n.d.)
Australia	GREEN STAR	Green Star Australia	2003	Green Building Council Australia (GBCA)	1,715	(“Why Green Star? | Green Building Council of Australia,” n.d.)
	NABERS™	National Australian Built Environment Ratings	2008	NSW (New South Whales Government)	2,736	(“NABERS,” n.d.)
New Zealand	GREEN STAR NZ	Green Star New Zealand	2007	New Zealand GBC	151	(“New Zealand Green Building Council,” n.d.)
Qatar	GSAS	Global Sustainability Assessment System	2009	The Gulf Organisation for Research and Development (GORD)	N/A	(“GSAS Trust | GSAS: Global Sustainability Assessment System | GORD,” n.d.)
Indian	LEED® India	Leadership in Energy and Environmental Design	2011	Indian Green Building Council (IGBC)	630	(“LEED India :: Green Building Information Gateway,” n.d.)
	TERI-GRIHA	TERI–Green Rating for Integrated Habitat Assessment	2007	The Energy & Research Institute (TERI)	1,200	(“Home | Green Rating for Integrated Habitat Assesment,” n.d.)
United Arab Emirates	Estidama	Pearl Rating System	2010	Abu Dhabi Urban Planning Council (UPC)	N/A	(Awadh, 2017)
Malaysia	MYCREST	Malaysian Carbon Reduction and Environmental Sustainability Tool	2013	Public Work Department Malaysia and Construction Industry Development Board	N/A	(“MyCrest,” n.d.)
	GBI	Green Building Index	2010	Malaysian Institute of Architects and the Association of Consulting Engineers Malaysia	412	(“Green Building Index,” n.d.)
Hong Kong	CEPAS	Comprehensive Environmental Performance Assessment Scheme for Buildings	2002	HK Building Department	N/A	(“主頁 - 屋宇署,” n.d.)
	HK BEAM PLUS	Building Environmental Assessment Method	1996	Green Building Council Limited de Hong Kong (HKGBC)	467	(“BEAM Plus New Buildings | Introduction - The Hong Kong Green Building Council (HKGBC) 香港綠色建築議會,” n.d.)
Taiwan	EEWH	EEWH Evaluation Manual	1999	Architecture and Building Research Institute	4,300	(“綠建築標章Q&A Green Building Label Questions and Answer,” n.d.)
China	GOBAS	Green Olympic Building Assessment System	2003	Minister of Science & Technology	N/A	(Zhang, Wang, Hu, & Wang, 2017)
	ESGB	Evaluation Standard for Green Building	2006	Ministry of Housing and Urban-Rural Development (MOHURD)	1,440	(Zhang et al., 2017)
	GBL	Green Building Labelling	2008	Ministry of Housing and Urban-Rural Development (MOHURD)	N/A	(Ye, Cheng, Wang, Lin, & Ren, 2013)

	GHEM	Green Housing Evaluation Manual	2002	China Real Estate Chamber of Commerce	N/A	(Bernardi, Carlucci, Cornaro, & Bohne, 2017)
Japan	CASBEE	Comprehensive Assessment System for Built	2001	Japan Sustainable Building Consortium (JSBC)	330	("CASBEE Certification System," n.d.)
South Korea	G-SEED	Green Standard for Energy and Environmental Design	2002	Ministry of Land, Infrastructure, & Transport (MOLIT)	1,723	("환경부, 국토교통부 녹색건축인증 지원시스템," n.d.)
Singapore	GREEN MARK	GREEN MARK	2005	BCA (Building and Construction Authority)	3,000	("Building & Construction Authority," n.d.)
Vietnam	LOTUS	LOTUS	2007	Vietnam Green Building Council (VGBC)	72	("VGBC | Vietnam Green Building Council," n.d.)
Egypt	GPRS	Green Pyramid Rating System	2011	The Egyptian Green Building Council	N/A	("Egyptian Green Building Council," n.d.)
Global	WELL	WELL Building Standard	2014	The International WELL Building Institute (IWBI); World GBC	834	("International WELL Building Institute |," n.d.)
			GROUP II: STANDARS			
Global	LEB	Low-energy buildings	1994	N/A	N/A	("LEB Technical reference | Low Energy Buildings," n.d.)
Germany	PASSIVHAUS	Passivhaus Standard	1990	The International Passive House Association	4,299	("Passivhaus Institut," n.d.)
U.K	ZCB	Zero Carbon Buildings	1994	N/A	N/A	(Hui, 2015)
United States of America	NZEB	Net Zero Energy Building	2000	International Living Future Institute	N/A	("NZEB," n.d.)
	NGBS	National Green Building Standard	2008	National Association of Home Builders (NAHB)	137,383	("What's National Green Building Standard (NGBS)," n.d.)
Mexico	CEV	Housing Building Code	2007	National Housing Commission (CONAVI)	N/A	("Código de Edificación de Vivienda (CEV) | Commission for Environmental Cooperation," n.d.)
Canada	BUILT GREEN®	BUILT GREEN	2001	BUILT GREEN	30,290	("Built Green," n.d.)
			GROUP III: TOOLS			
Canada	ATHENA™	Athena Impact Estimator for Buildings	2002	ATHENA Sustainable Material Institute	N/A	("IE for Buildings | Athena Sustainable Materials Institute," n.d.)
United States of America	BEES 4.0	Building for Environmental and Economic Sustainability	1998	NIST (National Institute of Standards and Technology)	N/A	("Building for Environmental and Economic Sustainability (BEES) | WBDG - Whole Building Design Guide," n.d.)
Holland	ECO-quantum	ECO-quantum	1999	Sustainability research and consultancy department of the University of Amsterdam (IVAM)	N/A	(Kumanayake & Luo, 2018)
United kindong	ENVEST II	ENVEST II	2003	Building Research Establishment	N/A	(Haapio & Viitaniemi, 2008)
United kindong	CCaLC Tool	Carbon footprinting tool	2007	University of Manchester	N/A	("Carbon Calculator Tools, Software and Support," n.d.)
France	ELODIE	ELODIE	2006	CSTB's Environment division	N/A	(Berardi, 2015)

	TEAM™	TEAM™	1995	Ecobilan	N/A	(Haapio & Viitaniemi, 2008)
	EQUER	EQUER	1995	Ècole des Mines de Paris, Centre d'Énergétique et Procédés	N/A	(Haapio & Viitaniemi, 2008)
	ESCALE	ESCALE	2000	CTSB and the University of Savoie	N/A	(Haapio & Viitaniemi, 2008)
	PAPOOSE	PAPOOSE	1997	TRIBU Architects	N/A	(Haapio & Viitaniemi, 2008)
Denmark	BEAT 2002	BEAT 2002	2000	Danish Building Research Institute (SBI)	N/A	(Haapio & Viitaniemi, 2008)
Germany	GABI	GABI	1999	IKP University of Stuttgart, PE Product Engineering GmbH	N/A	(Haapio & Viitaniemi, 2008)
	GEMIS	Global Emission Model of Integrated Systems	1990	Oeko-Institut (Institute for applied Ecology)	N/A	("GEMIS - IINAS," n.d.)
	LEGEP®	LEGEP®	2001	LEGEP Software GmbH	N/A	(Haapio & Viitaniemi, 2008)
	OpenLCA	OpenLCA	2013	GreenDeltaTC GmbH	N/A	("openLCA," n.d.)
	Umberto	Umberto	1994	Ifu Hamburg GmbH	N/A	("Life Cycle Assessment software- Umberto LCA+ Software," n.d.)
Netherlands	SIMAPRO	SIMAPRO	1990	Pre Consultants	N/A	("SimaPro | The World's Leading LCA Software," n.d.)
Italy	eVerdEE	eVerdEE	2004	ENEA	N/A	(Berardi, 2015)
Switzerland	Eco-Bat	Eco-Bat	2008	University of Applied Science of Western Switzerland	N/A	("Eco-Bat 4.0," n.d.)
Sweden	Miljöstatus	Environmental Status Model	1997	Association of the Environmental Status of Buildings	N/A	("Sweden Green Building Council," n.d.)
	EcoEffect	EcoEffect	2006	Royal Institute of Technology	N/A	(Haapio & Viitaniemi, 2008)
Finland	BeCosT	BeCosT	1996	Technical Research Centre of Finland (VTT)	N/A	("Sustainable Building - VTT Materials and Construction," n.d.)
Japan	AIST-LCA	AIST-LCA	1996	National Institute for Resource and Environment	N/A	("LCA-Center, AIST - Research Activities: Software AIST-LCA Ver.4," n.d.)
	AIJ-LCA	AIJ-LCA	2003	Japan Architectural Society	N/A	(Kumanayake & Luo, 2018)
	Carbon Navigator	Carbon Navigator	2009	Daisei construction	N/A	(Kumanayake & Luo, 2018)
	GEM-21P	GEM-21P	2008	Shimizu Corporation	N/A	(Kumanayake & Luo, 2018)
Korea	SUSB-LCA	SUSB-LCA	2007	Sustainable Building Research Center, Hanyang University	N/A	(Lee, Tae, & Shin, 2009)
	K-LCA	K-LCA	2004	Korea Institute of Construction Technology	N/A	(Baek, Park, Suzuki, & Lee, 2013)
	BEGAS	BEGAS	2013	Sustainable Building Research Center	N/A	(Roh, Tae, & Shin, 2014)
Australia	LISA	LCA In Sustainable Architecture	2003	BPH- Australia and Universidad de Newcastle y el Swedish Building Institute)	N/A	("LCA In Sustainable Architecture," n.d.)

United States of America	Energy Plus	Energy Plus	1998	U.S. Department of Energy (DOE)	N/A	(“EnergyPlus,” n.d.)
	TRNSYS	Transient System Simulation Tool	1975	University of Wisconsi	N/A	(“TRNSYS : Transient System Simulation Tool,” n.d.)
United kindong	Design Builder	Design Builder	N/A	DesignBuilder Software Ltd	N/A	(“DesignBuilder Software Ltd - Home,” n.d.)
Global	Ecotect	Ecotect	2005	Autodesk	N/A	(Yang, He, & Ye, 2014)
Spain	HULC	Herramienta Unificada LIDERCALENER	2015	Ministerio de Industria, Turismo y Comercio de España	N/A	(“Herramienta unificada LIDER-CALENER (HULC),” n.d.)
			LEVEL(S)			
European Union	LEVEL(s)	Building sustainability performance	2017	European Commission	N/A	(Dodd, Cordella, Traverso, & Donatello, 2017)

Table 3. Categories and assessment criteria

Category	(C1) SITE AND SUSTAINABLE DEVELOPMENT
Assessment criteria	
1	implantation in developed plot
2	urban design and site development
3	use of reused land
4	location in uncontaminated soil
5	location without risk of fire
6	location without seismic risk
7	location without risk of avalanches
8	location without irrigation of floods
9	location without volcanic risk
10	location without meteorological risk
11	use of vegetation as shade
12	stopping noise sources
13	building orientation
14	access to renewable energy sources
15	reduction light pollution
16	reduction acoustic pollution
17	water course pollution reduction
18	heat island effect
19	provision of open spaces
20	land management and runoff
21	impact reduction in construction areas
22	reduction of local impacts on biodiversity and ecology
23	development plans or environmental reports
24	improvement of the ecological value
25	restoration of the native flora and fauna
26	long-term biodiversity management plan
27	erosion and sedimentation control plan
28	accessibility of public transport
29	accessibility to public services

30	security and pedestrian access
31	promotion of sustainable vehicles
32	community transport plan
Category	**(C2) WATER**
Assessment criteria	
33	reduction consumption of drinking water
34	reduction consumption of non-potable water
35	measures to limit water consumption
36	efficient water consumption equipment
37	stop and prevent leaks
38	gray water reuse
39	reuse of rainwater
40	innovative wastewater technology
41	efficient irrigation system
42	monitoring of water consumption
43	use of native plants
44	use alternative sources of water
Category	**(C3) MATERIALS AND RESOURCE CONSUMPTION**
Assessment criteria	
45	construction waste management
46	demolition waste management
47	classification municipal solid waste
48	(MSW)
49	limitation of the generation of MSW
50	storage of MSW
51	system of revaluation of MSW
52	radioactive waste control
53	use of materials with low environmental impact
54	design oriented to the protection of materials and solutions
55	use of materials with high thermal inertia
56	use renewable materials
57	use of durable materials
58	use of recycled materials

59	re-use of existing structures
60	use of local materials
61	use of materials from sustainable sources
62	modular and standard design
63	ecolabelling of product.
64	environmental declarations of products
65	LCA tool for products
66	reduction of toxicity of materials
Category	**(C4) ENERGY**
Assessment criteria	
67	efficient thermal systems
68	efficient lighting systems
69	efficient escalator / elevator
70	super-insulating glass and frames
71	solutions to minimize heat losses
72	low consumption equipment
73	use of renewable energy in the transport of materials
74	use of renewable energy during the demolition phase
75	use of renewable energy during the use phase
76	renewable energy generated in situ
77	planning the use of the building
78	energy simulation
79	measurement and verification of energy consumption
80	thermal systems control
81	sectorization thermal systems
82	collective thermal systems
83	individual counters
84	green envelope
85	impact of orientation
86	passive solar collection
87	passive cooling
88	thermal inertia of materials and solutions
89	prevention of refrigerant leaks

90	green houses gases reduction measures
91	CO_2 mitigation
Category	**(C5) INDOOR ENVIRONMENTAL QUALITY**
Assessment criteria	
92	optimal noise level
93	optimal acoustic insulation
94	sound absorption
95	optimal background noise
96	natural light optimization
97	glare control
98	efficient lighting level
99	Views
100	control of artificial lighting
101	IAQ management plan during use
102	IAQ management plan during construction
103	promotion natural ventilation
104	efficient ventilation systems
105	air purification
106	tobacco smoke control
107	air quality control
108	reduction of carcinogens
109	formaldehyde level reduction
110	purge process
Category	**(C6) INNOVATION**
Assessment criteria	
111	exemplary performance
112	innovation in design
113	building as an educational tool
114	accredited professional
Category	**(C7) SOCIAL AND ECONOMY**
Assessment criteria	
115	regional priority
116	universal accessibility

117	open public space
118	right to privacy
119	sun burning
120	design compatible with cultural values
121	improve urban landscapes
122	use of traditional local materials and techniques
123	protection of heritage value
124	sustainable design without cost increase
125	calculation of the cost of the life cycle
126	life planning
127	study investment risk
128	studio rental affordability
129	impact of the project on the value of the adjacent land
130	impact of the project on the local economy
131	study commercial viability
Category	**(C8) SERVICE QUALITY**
Assessment criteria	
132	security and protection during operations
133	functionality and efficiency
134	flexibility and adaptability
135	optimization and maintenance of operational performance
136	durability and reliability
137	sustainable management
138	stakeholder participation
139	responsible construction practices
140	building management system
Category	**(C9) CIRCULAR ECONOMY**
Assessment criteria	
141	requirements for product design, dismantling and reparability
142	requirements for optimum waste handling
143	requirements for renewable, recycled and sustainable raw materials
144	strict chemical requirements
145	quality requirements and lifetime

Category	(C10) ADAPTATION CLIMATE CHANGE
Assessment criteria	
146	climate projections
147	vulnerability diagnosis
148	adaptation plan to climate change
149	monitoring and evaluation plan
150	resilient actions

Table 4. Relationship of each System with the 32 criteria belonging to category (C1)

	Group I (Systems)																					
ASSESSMENT CRITERIA	VERDE	BREEAM	HOE	ITACA	IHOBE	Estidama	NABERS	SBAT	DGNB	LEED	CASBEE	Green Star	BEAM PLUS	GREEN	SB TOOL	GREEN MARK	BOMA BEST	GBI	AOUA	ESGB	GSAS	%
implantation in developed plot		■	■	■	■	■		■	■	■	■	■	■	■	■	■	■		■	■	■	85,71%
urban design and site development			■	■	■	■	■	■	■	■	■	■	■	■	■		■			■	■	76,19%
use of reused land		■	■		■	■	■	■	■	■	■	■	■			■	■	■	■	■	■	80,95%
location in uncontaminated soil		■		■	■		■	■	■	■	■	■	■	■	■	■	■	■	■		■	80,95%
location without risk of fire		■						■	■	■			■	■	■							33,33%
location without seismic risk		■							■	■												14,29%
location without risk of avalanches		■						■	■	■												19,05%
location without irrigation of floods		■	■					■	■	■					■			■	■			38,10%
location without volcanic risk		■																				4,76%
location without meteorological risk		■		■				■	■	■												23,81%
use of vegetation as shade	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	100,00%
stopping noise sources			■	■		■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	80,95%
building orientation			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	90,48%
access to renewable energy sources								■	■	■	■	■	■	■	■	■	■	■	■	■	■	66,67%
reduction light pollution	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■		■	■		85,71%

reduction acoustic pollution	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■				■	80,95%
water course pollution reduction		■	■	■		■	■	■	■	■	■	■	■	■	■	■	■		■	■		80,95%
heat island effect	■		■		■	■	■	■	■			■	■	■	■			■		■	■	66,67%
provision of open spaces	■	■	■				■	■		■	■	■	■		■	■	■	■	■	■	■	76,19%
land management and runoff	■	■		■	■		■	■	■	■	■	■	■	■	■		■	■		■	■	80,95%
impact reduction in construction areas		■				■	■		■	■		■	■	■	■	■						52,63%
reduction of local impacts on biodiversity and ecology	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	95,24%
development plans or environmental reports				■								■		■	■	■						23,81%
improvement of the ecological value	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■	■	■	■	■	■	95,24%
restoration of the native flora and fauna	■		■	■	■	■	■	■	■			■	■	■	■	■	■	■	■	■	■	85,71%
long-term biodiversity management plan		■	■									■		■		■			■		■	33,33%
erosion and sedimentation control plan	■	■	■	■	■	■	■	■	■	■	■	■	■		■		■	■	■	■	■	90,48%
accessibility of public transport	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	100,00%
accessibility to public services	■	■		■	■	■	■	■	■	■	■	■	■		■	■	■	■	■	■	■	90,48%
security and pedestrian access	■	■		■	■	■	■	■	■	■	■	■	■		■	■	■	■	■	■	■	90,48%
promotion of sustainable vehicles	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		95,24%
community transport plan			■		■	■					■	■	■		■				■			38,10%
	42%	70%	61%	55%	58%	61%	61%	81%	82%	79%	64%	79%	76%	61%	79%	64%	64%	55%	64%	61%	63%	

Table 5. Relationship between the variables and methods

variables		System	Standars	Tools	Level(s)
		LEED v4	Passivhause	ATHENA™	
phase of life cycle applied	Desing	■	■	■	■
	Production	■		■	■
	Constrution	■		■	■
	Use	■	■		■
	Maintance	■		■	■
	Demolition			■	■
	Disposal	■		■	■
sustainability aspects assessed	Environment	■	■	■	■
	Society	■			■
	Economy	■			■
type and status of the project assessed	Existing building	■	■	■	■
	New building	■	■	■	■
	Residential building	■	■	■	■
	Office building	■	■	■	■
	Other type of building	■	■	■	
	Districts	■			
	Building product/component		■	■	
categories considered	(C1)Site and Sustainable Development	■			■
	(C2)Water	■		■	■
	(C3)Materials and Resource Consumption	■		■	■
	(C4)Energy	■	■	■	■
	(C5)Indoor Environmental Quality	■	■	■	■
	(C6)Innovation	■			■
	(C7)Social and Economy	■			■
	(C8)Service Quality	■			■
	(C9)Circular Economy	■			■
	(C10)Adaptation climate change				■