Informes de la Construcción
Vol. 71, 556, e321
octubre-diciembre 2019
ISSN-L: 0020-0883
https://doi.org/10.3989/ic.63707

Analysis of sustainable building rating systems in relation to CEN/TC 350 standards

Análisis de sistemas de valoración de la sostenibilidad en la edificación en relación con la norma CEN/TC 350

P. Huedo Dorda (*), B. López-Mesa (**), E. Mulet (***)

ABSTRACT

Numerous sustainability rating systems have been developed in the building sector. In this paper we distinguish between those whose aim is to allow companies striving for improved performance to gain an objective basis for communicating their efforts, such as LEED, and those that aim to communicate the life cycle environmental impact of goods, such as ATHENA Impact Estimator. We name the former effort-driven assessment and the latter data-driven assessment. This work undertakes a state-of-the-art review of all these assessment systems and assesses their effectiveness comparing the indicators used for assessment against the established standards by the Technical Committee (TC) 350 of the European Committee for standardization (CEN/TC 350). About 62% of the social and economic indicators remain unconsidered by the existing data-driven assessment tools, whereas effort-driven assessment tools have a higher consideration of social and economic aspects, with about half of the indicators unconsidered.

Keywords: Sustainability building rating systems, sustainability indicators, standards CEN/TC 350.

RESUMEN

En el sector de la construcción se han desarrollado numerosos sistemas de calificación de sostenibilidad. En este documento distinguimos entre aquellos que pretenden que las empresas que luchan por mejorar su sostenibilidad obtengan una base objetiva para comunicar sus esfuerzos, como LEED, y aquellos que evalúan el impacto medioambiental de los productos durante el ciclo de vida, como ATHENA Impact Estimador. Denominamos a los primeros, sistemas de evaluación basada en el esfuerzo y a los segundos, sistemas de evaluación basada en datos. Este trabajo revisa el estado del arte de estos sistemas y evalúa su efectividad comparando los indicadores utilizados con los estándares establecidos por el the Technical Committee (TC) 350 of the European Committee for standardization (CEN). Observamos que un 62% de los indicadores sociales y económicos propuestos por el CEN/TC 350 no son considerados por los sistemas de evaluación basados en datos mientras que los sistemas de evaluación basados en el esfuerzo tienen en cuenta aproximadamente la mitad de estos indicadores.

Palabras clave: *Sistemas valoración sostenibilidad edificación, indicadores, estándares CEN/TC 350.*

(*) Dr. in Architecture, Universitat Jaume I, Castellón de la Plana (Spain).
(**) Dr. in Architecture, Universidad de Zaragoza, Zaragoza (Spain).
(***) Dr. in Industrial Engineering, Universitat Jaume I, Castellón de la Plana (Spain).
Persona de contacto/*Corresponding author*: huedo@uji.es (P. Huedo)
ORCID: https://orcid.org/0000-0001-7327-9661 (P. Huedo); https://orcid.org/0000-0003-1458-7685 (B. Lopez-Mesa); https://orcid.org/0000-0003-4903-1273 (E. Mulet)

Cómo citar este artículo/*Citation*: Huedo Dorda, P.; López-Mesa, B.; Mulet, E. (2019). Analysis of sustainable building rating systems in relation to CEN/TC 350 standards. *Informes de la Construcción,* 71(556): e321. https://doi.org/10.3989/ic.63707

Recibido/*Received*: 05/03/2018
Aceptado/*Accepted*: 28/02/2019
Publicado on-line/*Published on-line*: 10/12/2019

1. INTRODUCTION

Buildings in their construction, occupancy, renovation, repurposing and demolition phases strongly impact the environment. Increasing awareness of the influence that the building sector has on the environment and its implications for humans has fostered the desire to measure the performance of buildings to help sustainable decision making. Sustainability rating systems are a means to deliver objective measures of a building's impact on ecosystems and human health and to assess progress towards sustainable development. Discussion on sustainability in the building sector has gained international recognition. Green Building Council (GBC), for example, has organised several major international conferences that have greatly contributed to develop sustainable building (1). The selection and weight of indicators is a key issue in numerous initiatives on measuring buildings' sustainability as this subject continues to be constantly discussed (2).

In 1992, the first certification system for building sustainability evaluation was created in the United Kingdom, by the official research institute BRE (Building Research Establishment). Since then, numerous systems have been developed that address the product (material) and/or building level. At the building level, there are numerous formal sustainability rating systems with a comprehensive perspective (3) in worldwide use today, of which LEED (2014) and BREEAM (2014) are the best known (4), (5), (6), (7). In this paper they are called CBEA (Comprehensive Building Environmental Assessment). There are also many tools, such as the ATHENA Impact Estimator for Buildings (2015), which provide a cradle-to-grave life cycle inventory profile for a whole building. Herein they are known as BSIS (Building Sustainability Indicator System).

For constructions products there are declaration systems that aim to communicate the life cycle environmental impact of goods, the Environmental Product Declarations (EPD) of construction products (ISO 21930: 2017, ISO 14025:2006), and voluntary programmes that promote environmentally sound products by awarding them a distinctive symbol of environmental quality, namely Environmental Labels - Type I (ISO 14024:2018).

The primary role of CBEA and Environmental Labels is to provide a comprehensive assessment of the environmental characteristics of buildings or products that allows developers or manufacturing companies striving for improved performance to gain an objective basis for calculating their efforts. The main objective of the EPD of construction products, the BSIS and the LCIA methods is to measure energy and mass flows to assess progress towards sustainability. Assessments are effort-driven in the first group of tools, and the distinctive symbol is obtained provided that the product or building fulfils certain criteria. In the second group of tools assessments are data-driven and based on the Life Cycle Assessment (LCA) methodology (Table 1).

Kajikawa et al. (8) pointed out that a challenge in CBEA systems is to include more powerful analytical and design tools capable of integrating diverse knowledge and tools such as LCAs, life cycle cost accounting, computer-aided design, materials and inventory databases, etc., to offer credible and salient solutions.

The distinction between effort-driven and data-driven assessment approaches reveals that whereas in the former the importance is given to place a building's or product's performance on a relative scale (the best assessed should be those making greater efforts), in the latter the importance is given to obtain an absolute value and the methodology to do so is often under consideration. Whereas effort-driven assessment has largely spread throughout the professional world due to its higher ease of use, data-driven assessment is a matter of continuous discussion in the scientific world. One of the challenges nowadays is how to integrate these two models.

More recently in order to find a common European approach, the European Committee for Standardization (CEN/TC 350) has developed two types of standards for the sustainability assessment of buildings (EN 15643-2:2011 and EN 15978:2011) and for the sustainability assessment of construction products (CEN/TR 15941:2010, EN 15942:2011, EN 15804:2012+A1:2013).

The standard for buildings provides specific principles and requirements to assess the environmental performance of buildings by taking into account the technical characteristics and functionality of a building. The calculation method is based on the Life Cycle Assessment (LCA).

With construction products, environmental product declarations (EPD) are, according to Standard ISO 14020, Type III Environmental Labels, which are voluntary in nature, and present information about the environmental behaviour of products based on LCAs, which fulfil both ISO 14040 and 14044, they must be verified independently and be in accordance with agreed guidelines.

This work undertakes a state-of-the-art review of all the building assessment systems and assesses their effectiveness comparing the indicators used for assessment against the recently established standards by the CEN for sustainability assessment indicators in the building sector, what is of interest in order to achieve harmonisation in sustainability building assessments and in environmental declarations of construction products.

Unlike other studies that have already been conducted and have compared different assessment systems, this article centres on the effectiveness of those systems considered according to the recommendations made by the CEN in terms of indicators.

Table 1. Types of assessment of the different sustainability rating systems.

	Whole building	Construction products
Effort-driven assessment	CBEA (LEED, BREEAM, etc.)	Environmental labels – type 1
Data-driven assessment	BSIS (ATHENA Impact Estimator for Buildings, etc.)	EPD of construction products
	Life Cycle Impact Assessment (LCIA)	

2. METHODOLOGY

This article has followed the steps shown in Figure 1, further explained next:

- In the first place, the standards published by the CEN were analysed.
- Secondly, the data-driven assessments more widely used in different countries were selected, classified and cross-sectional studied. Then a comparative study of the indicators considered by these methods with the indicators recommended by the CEN was conducted.
- Thirdly, internationally recognised effort-driven assessments were selected, classified and cross-sectional studied. Finally, a comparison was made of the indicators considered by these assessment systems with the indicators recommended by the CEN.

Sustainability indicators proposed by the CEN for buildings and products

The International Standards Organization (ISO) defines a standard as: 'a document, established by consensus, approved by a recognized body that provides for common and repeated use as rules, guidelines, or characteristics for activities or their results.' The Technical Committee (TC) 350 of the CEN, named 'Sustainability of Construction Works', has developed voluntary horizontal standardised methods to assess the sustainability aspects of new and existing construction works, and for standards for the environmental declaration of construction products (table 2).

It is worth mentioning the existence of another standard published by the International Organisation for Standardisation, named ISO/TS 21929-1.2009 –Sustainability in the construction of buildings - Sustainability Indicators. Part 1: Framework

It is worth mentioning the existence of another standard published by the International Organisation for Standardisation, named ISO/TS 21929-1.2009 –Sustainability in the construction of buildings - Sustainability Indicators. Part 1: Framework to develop indicators for buildings.

All these standards identify the environmental indicators in Table 3 for the assessment of buildings. They reveal the importance of using a system of Sustainability Indicators for the sustainable certification of a project, for decision making, and for indicators to be internationally comparable. Even if this paper focuses on the assessment of buildings sustainability, it is of interest to note that the indicators suggested by the CENT/TC 350 for environmental product declarations are the same.

The World Commission on Environment and Development`s definition of sustainability (9) states that development must simultaneously consider the environmental, economic and social dimensions, which is a holistic and interdisciplinary approach (10), (11), (12), (13) suggested that environmental sustainable development objectives should be acknowledged and addressed in interventions designed to address social and economic priorities. (14) stated that the green building approach should consider three dimensions: environmental, social, and economical. Therefore, the assessments must take these three dimensions into account. In this way, a sustainable idea also expresses the interconnected nature of these three areas and leads to an economically feasible, socially viable and environmentally responsible project outcome (15), (16).

Table 2. Standards developed by CEN/TC 350 on the sustainability of construction works.

Scope	Published standards
Sustainability assessment of buildings	EN 15643-1:2010 Sustainability of construction works - Sustainability assessment of buildings - Part 1: General framework EN 15643-2:2011 Sustainability of construction works - Assessment of buildings - Part 2: Framework for the assessment of environmental performance EN 15643-3:2012 Sustainability of construction works - Assessment of buildings - Part 3: Framework for the assessment of social performance EN 15643-4:2012 Sustainability of construction works - Assessment of buildings - Part 4: Framework for the assessment of economic performance EN 15978:2011[1] Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method EN 16309:2014+A1:2014 Sustainability of construction works - Assessment of social performance of buildings - Calculation methodology ISO/TS 21929-1.2009 –Sustainability in the construction of buildings - Sustainability Indicators. Part 1: Framework to develop indicators for building
Environmental product declarations	CEN/TR 15941:2010 Sustainability of construction works - Environmental product declarations - Methodology for selection and use of generic data EN 15804:2012+A1:2013[2] Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products EN 15942:2011 Sustainability of construction works - Environmental product declarations - Communication format business-to-business

[1] EN 15978 is going to be revised.
[2] EN 15804 is under revision.

Table 3. The environmental indicators suggested by CEN/TC 350 for buildings and products.

	Units	Scope	
		Building	**Product**
Indicators describing environmental impacts			
Global warming potential, GWP	kg Eq CO_2, 100 years	✓	✓
Stratospheric ozone layer depletion potential, ODP	kg Eq CFC-11	✓	✓
Acidification potential of soil and water, AP	kg Eq SO_2	✓	✓
Eutrophication potential, EP	kg Eq $(PO_4)^3$	✓	✓
Formation potential of tropospheric ozone, POCP	kg Eq C_2H_4	✓	✓
Abiotic depletion potential for non-fossil resources, ADP-elements	kg Eq Sb	✓	✓
Abiotic depletion potential for fossil fuels	MJ, net calorie value	✓	✓
Indicators describing resources use			
Use of renewable primary energyexcluding renovable primary energy resources used as raw materials, PERE	MJ, net calorific value	✓	✓
Use of renewable primary energy resources used as raw materials, PERM	MJ, net calorific value	✓	✓
Total use of renewable primary energy resources, PERT	MJ, net calorific value	✓	✓
Use of non-renewable primary energy excluding no-renewable primary energy resources used as raw materials, PENRE	MJ, net calorific value	✓	✓
Use of non-renewable primary energy resources used as raw materials, PENRM	MJ, net calorific value	✓	✓
Total use of non-renewable primary energy resources, PENRT	MJ, net calorific value	✓	✓
Use of secondary materials	kg	✓	✓
Use of renewable secondary fuels, RSF	MJ, net calorificvalue	✓	✓
Use of non-renewable secondary fuels, NRSF	MJ, net calorie value	✓	✓
Use of fresh water, FW	m^3	✓	✓
Indicators describing complementary environmental information			
Hazardous waste, HWD	kg	✓	✓
Non-hazardous waste, NHWD	kg	✓	✓
Radioactive waste disposed (total low, intermediate and high level waste), RWD	kg	✓	✓
Radioactive waste (level waste), RWD	kg	✓	✓

Within the social frame, Standard EN 15643-3:2012 establishes some generic categories of indicators completed with calculation methods. The intention of this Standard is for the assessment results to be compared between different countries by focusing on the social behaviour of both new buildings in their entire life cycle and existing buildings for their remaining useful life.

The social categories included to describe a building's social behaviour are provided in Table 4.

Table 4. The social indicators suggested by UNE-EN 15643-3:2012.

Social Indicators	**Suggested impact categories**
Accessibility	Access for people with specific needs, access to certain building services
Adaptability	Capacity to be adapted to a given user's requirements Capacity to be adapted to a change in users' requirements Capacity to be adapted to technical changes Capacity to be adapted to use changes.
Health and comfort	Sound characteristics Quality of indoor air Visual comfort Thermal comfort Water quality Electromagnetic characteristics Spatial characteristics
Burdens on neighbours	Noise Emissions to the atmosphere, land and water, Glare and overshading Impacts and vibrations Effects of wind
Maintenance	Maintenance operations (including health and confort issuesfor users and neighbours)
Security	Resistance to climate change (rain, wind, snow, floods, solar radiation, temperature) Resistance to accidental situations (Earthquakes, explosions, fire, traffic impacts) Security against vandalism and intruders Security against interruptions in supplies
Origin of materials and services	Responsible and traceable origin of assets and services
Implication of stakeholders	Opportunities for the stakeholders to participate in decision-making processes

Assessing social behaviour differs from economic or environmental assessments in that it requires an approach that is both quantitative and qualitative. When it is not possible to obtain quantitative results, checklists are typically used.

Within the economic frame, Standard EN 15643-4 : uses economic indicators to measure economic flows, such as investment, design, construction, making products, use, energy use, water use, waste, maintenance, deconstruction, developing the project's economic value, the income made by the project and its services, etc. The economic indicators included to describe a building's economic flows are shown in Table 5.

Next, the internationally recognised sustainability evaluation systems were selected, classified and cross-sectional studied by considering both effort-driven and data-driven assessments, and then checking if these indicators are included by data-driven and effort-driven methods, or not.

Data-driven sustainability assessment: the scientific method

Data-driven assessment tools are based on LCA, a methodology to assess the environmental impact of a given product or building throughout its lifespan. The term 'life cycle' refers to the notion that it must be holistic for a fair assessment; i.e. all phases need to be assessed, including raw material production, manufacture, distribution, use and disposal, as well as all the intervening transportation steps.

LCA procedures are described in ISO 14040:2006 and 14044:2006 as part of the ISO 14000 environmental management standards. According to ISO 14044, the main phases of a LCA are: Goal & Scope; Inventory Analysis; Impact Assessment; and Interpretation.

The first impact assessment step consists of drawing up an inventory list of all the input and output environmental flows of a product system. However, as a long list of substances is difficult to interpret, a further step is needed in impact assessments, known as a life cycle impact assessment (LCIA). An LCIA consists of 4 steps:

- Classification: all the substances are sorted into classes according to the effect that they have on the environment.
- Characterisation: all the substances are multiplied by a factor that reflects their relative contribution to an environmental impact.
- Normalisation (optional step): the quantified impact is compared to a certain reference value; e.g., the average environmental impact of a European citizen in 1 year.
- Weighting (optional step): different value choices are given to the impact categories to generate a single score.

According to this information, the impact categories can be used as indicators.

Effects on the environment considered by the different methods to conduct LCIA

For each substance, a schematic cause-effect chain needs to be developed that describes the environmental mechanism of the emitted substance. During this environmental mechanism, an impact category indicator result can be chosen at either the midpoint or the endpoint level.

Midpoints are considered to be links in the cause-effect chain of an impact category, prior to endpoints. Midpoint methods (CML 92, CML2001 version Baseline, EDIP 2003, EPD 2007, TRACI 2) are problem-oriented and translate impacts into environmental themes, such as ozone depletion, global warming and smog creation. Some methodologies (EPS 2000, Eco-indicador 95, Eco-indicador 99, IMPACT 2002+, IPCC 2001 GWP) have adopted characterisation factors at an endpoint level in the cause-effect chain. This is a damage-oriented approach that translates environmental impacts into issues of concern, such as human health in terms of disability adjusted life years for carcinogenicity or impacts in terms of changes in biodiversity (17). Endpoint results have a higher level of uncertainty compared to midpoint results, but are easier to understand by decision makers. Table 6 classifies the Endpoint-type impacts with the indicators considered by CEN/TC 350, and indicates which impact assessment methods (LCIA) evaluated them. Figure 1 shows the percentage of CEN suggested indicators considered in each LCIA tool.

Table 5. The economic indicators suggested by UNE-EN 15643-3:2012.

Economic Indicators	Impact Categories
Cost	Investment cost Explotation and maintenance cost Demolition and waste management cost
Financial value	Investment financial cost Exploitation and maintenance financial cost Demolition and waste management financial cost
Ratio between market value and capital cost	Ratio between market value and capital cost at the building work completion
Verification of value versus future stability of economic value	Value versus future stability of economic value by undertaking analysis of financial scenarios and/or Monte-Carlo simulation, or alternatively techniques of clasiffication of ownership
Economic risk	Stability of economic value by undertaking analysis of financial scenarios and/or Monte-Carlo simulation, or alternatively techniques of clasiffication of ownership
External costs	External costs
Results economic aspects	Economic aspects relating to energy efficiency level (relative to a high energy cost) Economic aspects relating to adaptability to use or users' requirements changes Economic aspects relating to intrinsic risks in localisation Economic aspects relating to accessibility Economic aspects relating to spatial efficiency

Table 6. Comparison of the indicators considered by CEN and the endpoint effects considered by different methods for LCIA.

Environmental indicators suggested by CEN/TC 350		ENDPOINT-TYPE effects Damage category	IMPACT ASSESSMENT METHODS									
			CML 92	CML 2011	EDIP 2003	EPD 2007	TRACI 2	EPS 2000	INDICATOR 95	INDICATOR 99	IMPACT 2002	IPCC 2001
Indicators describing environmental impacts	Global Warming Potential (GWP), kg.Eq.CO_2	Climate change	1	1	1	1	1			1	1	1
	Stratospheric ozone depletion potential (ODP)	Damage to ecosystem	1	1	1	1	1			1	1	
	Acidification potential, kg SO_2 eq.		1	1	1	1	1			1	1	
	Eutrophication potential, kg PO_4 eq.		1	1	1	1	1			1	1	
	Photochemical smog potential, kg C_2H_4 eq.		1	1	1	1	1					
	Abiotic depletion potential for non-fossil resources, ADP-elements											
	Abiotic depletion potential for fossil resources, ADP-fossil fuels											
Indicators describing resources use	Use of renewable primary energy excluding renovable primary energy resources used as raw materials ,PERE. MJ, net calorific value	Damage to using resources										
	Use of renewable primary energy resources used as raw materials ,PERM. MJ, net calorific value											
	Total use of renewable primary energy resources ,PERT. MJ, net calorific value											
	Total use of renewable primary energy resources ,PERT. MJ, net calorific value											
	Use of non-renewable primary energy excluding no-renewable primary energy resources used as raw materials , PENRT. MJ, net calorific value											
	Total use of non-renewable primary energy resources ,PENRT. M.J, net calorific value											
	Use of secondary materials kg		1	1		1	1		1	1	1	
	Use of non- renewable secondary fuels, RSFS, MJ, net calorific value		1	1								
	Use of renewable secondary fuels, RSF MJ, net calorific value		1	1								
	Use of fresh water, m³						1					
Indicators describing complementary environmental information	Hazardous waste, kg											
	Non-hazardous waste, kg											
	Radioactive waste, kg				1							
Total no. of coincidences			8	8	6	6	7	0	1	5	5	1
			40%	40%	30%	30%	35%	0%	5%	25%	25%	5%
Social Indicators suggested by CEN/TC 350		ENDPOINT-TYPE effects Damage category										
Accessibility	For people with specific needs											
Adaptability	To a change in users' requirements											
	To technical changes											
	To use changes											
Health and comfort	Sound characteristics											
	Quality of indoor air											
	Visual comfort											
	Thermal comfort											
	Water quality											
	Electromagnetic characteristics											
	Spatial characteristics											
		Damage to health*	1	1	1	1	1	1	1	0	1	
Burdens on neighbours	Noise											
	Emissions to the atmosphere, land, water	Damage to using resources	1	1	1						1	
	Glare and overshading											
	Impacts and vibrations											
	Effects of wind											
Maintenance	Maintenance operations (including health and confort issues for users and neighbours)											
Security	Resistance to climate change (rain, wind, snow, floods, solar radiation, temperature)											
	Resistence to accidental situations (Earthquakes, explosions, fire, traffic impacts)											
	Security against vandalism and intruders											
	Security against interruptions in supplies											
	Security against interruptions in supplies											
Origin of materials and services	Responsible and traceable origin of assets and services											
Implication of stakeholders	Opportunities for the stakeholders to participate in decision-making processes											
Total no. of coincidences			2	2	2	1	1	1	1	0	2	0
			8%	8%	8%	4%	4%	4%	4%	0%	8%	0%

Table 6. Comparison of the indicators considered by CEN and the endpoint effects considered by different methods for LCIA *(Continuation)*.

Economic Indicators suggested by CEN/TC 350		ENDPOINT-TYPE effects Damage category	IMPACT ASSESSMENT METHODS									
			CML 92	CML 2011	EDIP 2003	EPD 2007	TRACI 2	EPS 2000	INDICATOR 95	INDICATOR 99	IMPACT 2002	IPCC 2001
Cost	Investment cost											
	Explotation and maintenance cost											
	Demolition and waste management cost											
Financial value	Investment fiancial cost											
	Explotation and maintenance l cost											
	Demolition and waste management cost											
Ratio between market value and capital cost	Ratio between market value and capital cost at the building work completion											
Verification of value versus future stability of economic value	Value versus future stability of economic value or alternatively techniques of clasification of ownership											
Economic risk	Stability of economic value by undertaking analysis of financial scenarios clasification of ownership											
External costs	External costs											
Results economic aspects	Energy efficiency level (relative to a high energy cost)											
	Adaptability to use or users' requirements											
	Intrinsic risks in localisation											
	Accessibility											
	Spatial efficiency											
Total number of coincidences			0	0	0	0	0	0	0	0	0	0
			0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

* Damage to health indicators assess mainly the effects related to the human toxicity resulting from direct exposure to chemicals. Health effects caused by other mechanisms of action (e.g. impacts from fine particles, from noise, etc.) are not included.

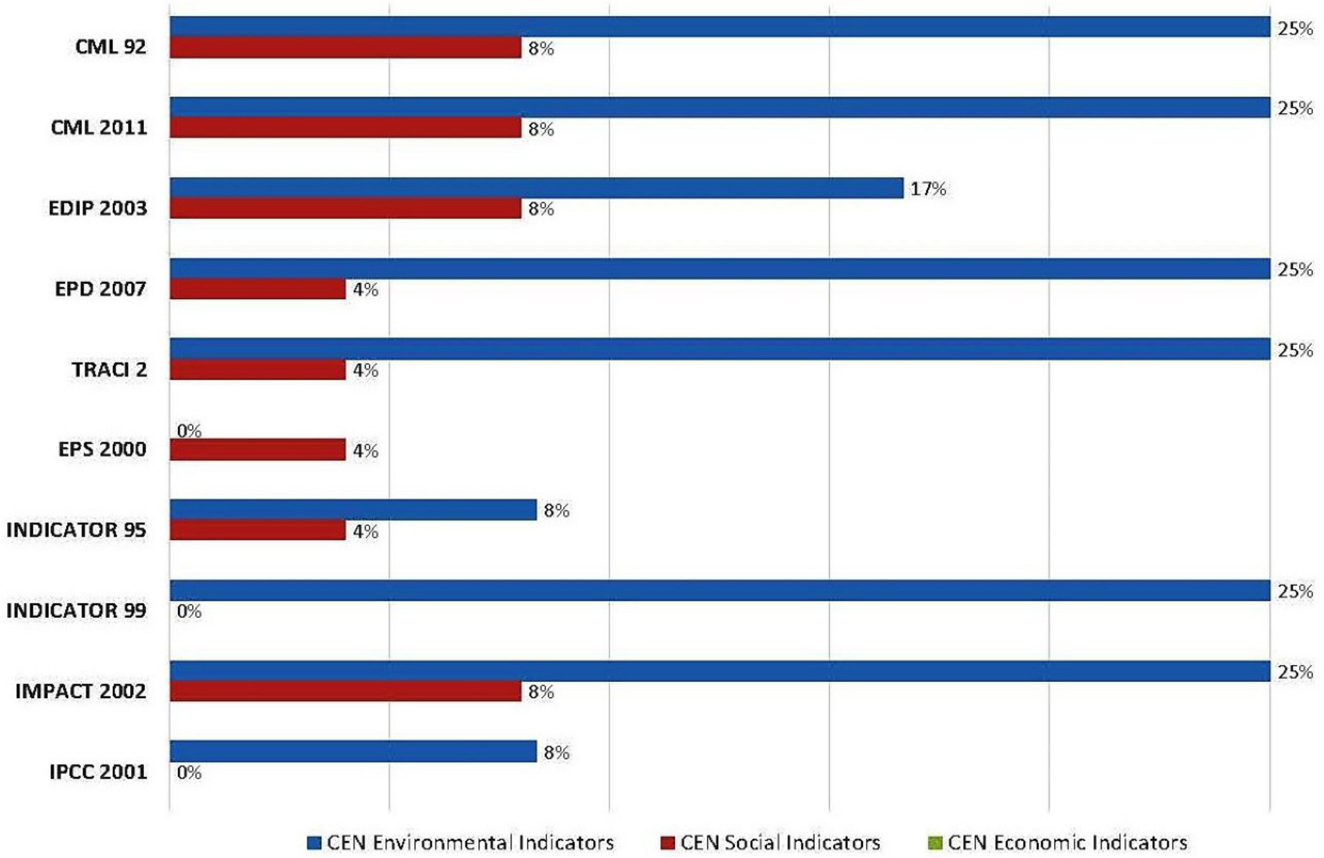

Figure 1. Proportion of the indicators suggested by CEN considered as Endpoint type impacts in different LCIA tools.

As can be seen, tools with a higher proportion of CEN indicators implemented as Endpoint impacts are CML92 and CML2011, with the 40% of the environmental indicators (climate change, damage to ecosystem and damage to using resources) and the 8% of the social indicators (damage to health and emissions to the atmosphere, land and water). TRACI2 include the same but without the emissions to the atmosphere, land and water and use of secondary fuels. The other tools include even less than these do. None of them includes economic indicators.

Table 7 classifies the Midpoint-type impacts compared to the indicators considered by CEN/TC 350 by indicating which impact assessment methods (LCIA) evaluate them. Figure 2

Table 7. Comparison of the indicators considered by CEN and the Midpoint effects contemplated by different methods for LCIA.

Environmental indicators suggested by CEN/TC 350		MIDPOINT-TYPE EFFECTS		IMPACT ASSESSMENT METHODS									
		Damage category	Damage subcategory	CML 92	CML 2011	EDIP 2003	EPD 2007	TRACI 2	EPS 2000	INDICATOR 95	INDICATOR 99	IMPACT 2002	IPCC 2001
Indicators describing environmental impacts	Global Warming Potential (GWP), kg.Eq.CO_2	Global Warming Potential (GWP), kg.Eq.CO_2		1	1	1	1	1			1	1	1
	Stratospheric ozone depletion potential (ODP)	Stratospheric ozone depletion potential (ODP)		1	1	1	1	1			1		
	Acidification potential, kg SO_2 eq.	Acidification potential, kg SO_2 eq.		1	1	1	1	1			1	1	
	Eutrophication potential, kg PO_4 eq.	Eutrophication potential, kg PO_4 eq.		1	1	1	1	1			1	1	
	Photochemical smog potential, kg C_2H_4 eq.	Photochemical smog potential, kg C_2H_4 eq.		1	1	1	1	1			1	1	
	Abiotic depletion potential for non-fossil resources, ADP-elements	Abiotic depletion potential for resources		1	1	1	1	1			1	1	
	Abiotic depletion potential for fossil resources, ADP-fossil fuels												
Indicators describing resources use	Use of renewable primary energy excluding renovable primary energy resources used as raw materials ,PERE. MJ, net calorific value	Use of abiotic resources, kg eq.	Use of renewable primary energy, MJ										
	Use of renewable primary energy resources used as raw materials ,PERM. MJ, net calorific value												
	Total use of renewable primary energy resources ,PERT. MJ, net calorific value												
	Total use of renewable primary energy resources ,PERT. MJ, net calorific value												
	Use of non-renewable primary energy excluding no-renewable primary energy resources used as raw materials , PENRT. MJ, net calorific value		Use of non-renewable primary energy, MJ	1								1	
	Total use of non-renewable primary energy resources ,PENRT. M.J, net calorific value												
	Use of secondary materials kg		Use of metals and minerals,kg	1	1					1	1	1	
	Use of non- renewable secondary fuels, RSFS, MJ, net calorific value		Use of non renewable fuels, MJ	1	1		1	1		1	1	1	
	Use of renewable secondary fuels, RSF MJ, net calorific value		Use of renewable fuels, MJ										
	Use of fresh water, m^3	Use of fresh water											
Indicators describing complementary environmental information	Hazardous waste, kg	Waste kg	Hazardous waste, kg			1							
	Non-hazardous waste, kg		Non-hazardous waste, kg			1							
	Radioactive waste, kg		Radioactive waste, kg			1							
Total no. of coincidences				9	8	9	7	7	0	2	8	8	1
				45%	40%	45%	35%	35%	0%	10%	40%	40%	5%
Social Indicators suggested by CEN/TC 350		**Damage category**	**Damage subcategory**										
Accessibility	For people with specific needs												
Adaptability	To a change in users' requirements												
	To technical changes												
	To use changes												
Health and comfort	Sound characteristics												
	Quality of indoor air												
	Visual comfort												
	Thermal comfort												
	Water quality												
	Electromagnetic characteristics												
	Spatial characteristics												

Table 7. Comparison of the indicators considered by CEN and the Midpoint effects contemplated by different methods for LCIA *(Continuation)*.

Social Indicators suggested by CEN/TC 350		MIDPOINT-TYPE EFFECTS		IMPACT ASSESSMENT METHODS									
		Damage category	Damage subcategory	CML 92	CML 2011	EDIP 2003	EPD 2007	TRACI 2	EPS 2000	INDICATOR 95	INDICATOR 99	IMPACT 2002	IPCC 2001
Burdens on neighbours	Noise												
	Emissions to the atmosphere, land, water	Toxicity	Emissions to the atmosphere, land, water	1	1	1						1	
	Glare and overshading												
	Impacts and vibrations												
	Effects of wind												
Maintenance	Maintenance operations (including health and confort issues for users and neighbours)												
Security	Resistance to climate change (rain, wind, snow, floods, solar radiation, temperature)												
	Resistence to accidental situations (Earthquakes, explosions, fire, traffic impacts)												
	Security against vandalism and intruders												
	Security against interruptions in supplies												
	Security against interruptions in supplies												
Origin of materials and services	Responsible and traceable origin of assets and services												
Implication of stakeholders	Opportunities for the stakeholders to participate in decision-making processes												
Total no. of coincidences				1	1	1	0	0	0	0	0	1	0
				4%	4%	4%	0%	0%	0%	0%	0%	4%	0%
Economic Indicators suggested by CEN/TC 350			ENDPOINT-TYPE effects Damage category										
Cost	Investment cost												
	Explotation and maintenance cost												
	Demolition and waste management cost												
Financial value	Investment fiancial cost												
	Explotation and maintenance l cost												
	Demolition and waste management cost												
Ratio between market value and capital cost	Ratio between market value and capital cost at the building work completion												
Verification of value versus future stability of economic value	Value versus future stability of economic value or alternatively techniques of clasification of ownership												
Economic risk	Stability of economic value by undertaking analysis of financial scenarios clasification of ownership												
External costs	External costs												
Results economic aspects	Energy efficiency level (relative to a high energy cost)												
	Adaptability to use or users' requirements												
	Intrinsic risks in localisation												
	Accessibility												
	Spatial efficiency												
Total number of coincidences				0	0	0	0	0	0	0	0	0	0
				0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

depicts the percentage of CEN indicators considered in the Midpoint-type impacts.

Regarding the Midpoint level impacts, in general, LCIA tools applied a higher number of the CEN indicators. CML2 and EDIP 2003 are the most complete ones with the 45% of the environmental indicators and the 4% of the social ones. Only use of primary energy, use of materials, use of fuels and use of fresh water are not considered in EDIP2003. As can be seen in Table 7, some of the tools take into account the use of fuels and the use of metals and minerals although the overall number of indicators is lower than in EDIP. The only one social indicator considered in four LCIA tools is the emissions to the atmosphere, land and water. Again, economic indicators are not implemented in these tools.

Formulating indicators becomes a key element to assess sustainability. To this end, it is necessary to associate one impact or more with the indicator, which supplies a numerical value and its measurement unit (kWh/m2 year, kg CO2 eq./m2 year, l/person day). Indicators can derive from qualitative and quantitative measures, but they only become standardised and comparable when transformed numerically (18).

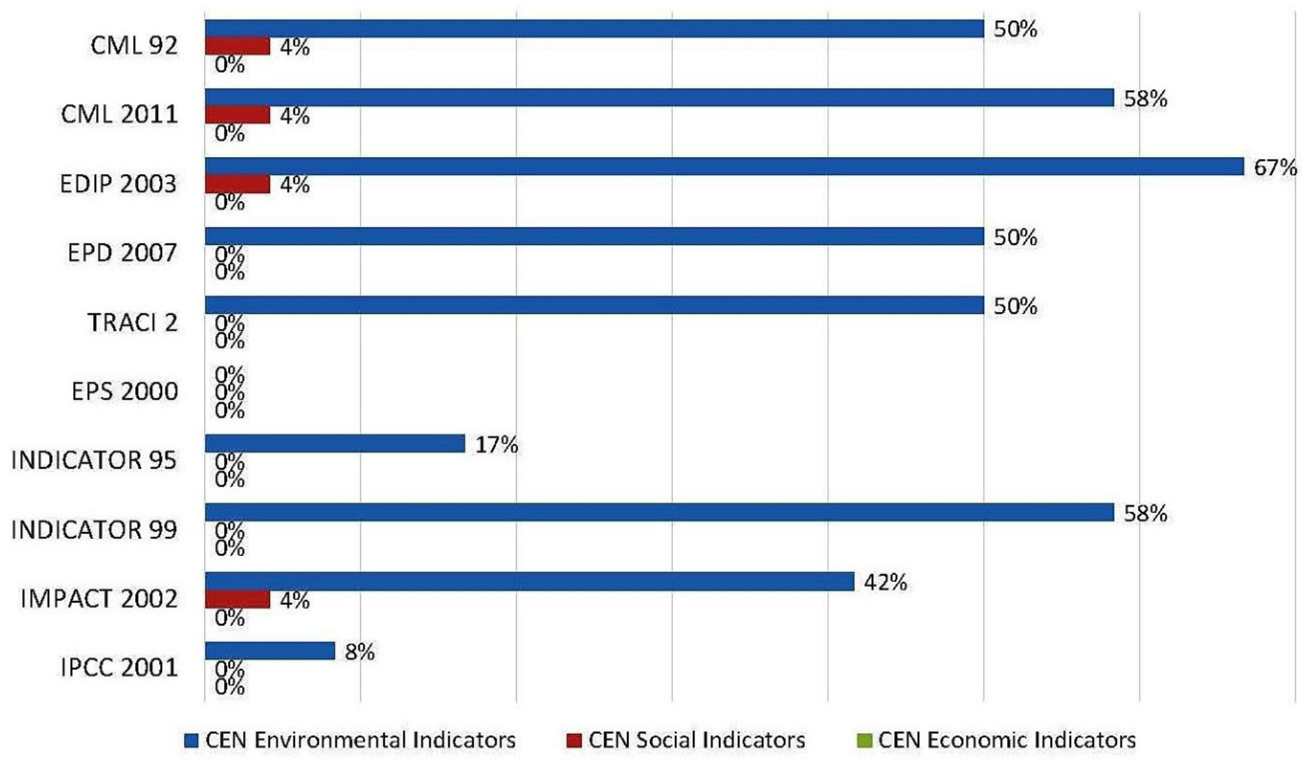

Figure 2. Proportion of the indicators suggested by CEN considered as Midpoint type impacts in different LCIA tools.

The sustainability indicators proposed in BSIS

Table 8 shows a list of LCA methodology-based tools developed in various organisations used exclusively to assess buildings or their components. These tools have been selected, because they can be used in the initial design phase, and allow the value of impacts to be obtained in real time by covering the different life cycle phases of buildings (19) .

As previously mentioned, all the tools shown in Table 8 are based on LCA. However, most of these tools only consider impacts due to materials during the whole building life cycle, but do not consider the impacts due to the use of building installations during its service life.

Tables 9, 10 and 11 compare the indicators established by the CEN/TC 350 with the indicators considered by Data-driven assessments.

Figure 3 shows the percentage of CEN indicators considered in the data-driven assessment tools.

As can be seen, BSIS are fundamentally based on LCA impact assessments. Among them, the global warming, stratospheric ozone depletion, acidification, eutrophication, and photochemical smog potentials, as well as energy use, are the impacts mainly considered by effort-driven assessments.

The tools that best adapt to environmental indicators set by the CEN are Beat 2002, BEES, Eco-Bat, Envest2, LCAid and TCQ2000, with 7 or 8 coincidences with the indicators set by the CEN.

EQUER is the one with more social indicators, considering 4 from the 25 set by the CEN. Generally speaking, these tools barely consider social indicators, and only BEES, Eco-effect and Envest consider air quality matters, assessed from the social perspective. BeCost, BEES, Eco-Bat, Envest2 and LISA are the only methods, along with Eco-quantum, that include CEN economic indicators.

Effort-driven sustainability assessment: the pragmatic method

An existing study (20) discusses that comprehensiveness in CBEA methods affords benefits and limitations. The main benefit is the wide scope of the evaluation as different sustainable design perspectives are considered. CBEA systems usually use the existing regulations to set benchmarks or qualification minimums or quantify the number of data-driven assessment elements used in the project, such as EPD, to award points, or use the energy certification obtained with simulation software like Energy Plus to assess the behaviour in the use phase. The limits result from the mixture of quantitative and qualitative measures and the weighting outlines of those measures, when different perspectives are integrated into a single criterion.

Many methodologies have been developed to establish the degree of accomplishment of environmental goals by guiding the planning and design processes. In these earlier construction process stages, planners can make decisions to improve building performance at very little or no cost following the recommendations of the decision-making tool (21).

The first outlines to voluntarily adopt sustainability criteria in the design, construction and/or operation of buildings appeared in the UK, where the official Building Research Establishment has worked since 1992 to develop them. The first commercially available method was BREEAM (the BRE

Table 8. Comparative frame. Tools based on LCA developed specifically to assess construction products, building systems or building, BSIS.

		ATHENA IMPACT ESTIMATOR	BEAT 2002	BECOST	BEES	ECO-BAT	ECO-CALCULATOR	ECO-EFFECT	ECO-QUANTUM	ECOSOFT	ENER-BUILCA	ENVEST 2	EQUER	LCAID	LEGEP	LISA	TCQ 20000	OFEN
ORIGIN		USA	DENMARK	FINLAND	2001 JAPAN	2003 AUSTRALIA	2001 CANADA	2006 SWEDEN	2005 FRANCE	2008 GERMANY	SPAIN	UK	FRANCE	AUSTRALIA	GERMANY	AUSTRALIA	SPAIN	SWITZERLAND
ORGANISATION		Athena Institute, USA.	SBi (Building Research Institute	Tarja Häkkinen, VTT	JSBC Japan	GBC Australia	ECD BOMA Canada	MINERGIE Association	HQE / AFNOR	GBC Germany	SUDOE	BRE Group	Ecole des Mines de Paris	NSW University of Western	GmbH	University of Newcastle	Institut de Tecnologia Construcció Catalonia	Office fédérale l'énergie (OFEN)
SCOPE / EXTENSION																		
ASSESSABLE PHASES	Construction	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Use	x				x		x	x	x	x	x	x	x	x	x	x	x
	Maintenance	x	x	x	x		x			x		x		x	x	x		
	Demoltiion	x	x	x	x	x	x	x	x	x	x	x	x	x	x			
ASSESSMENT METHOD																		
MÉTHODS	Own	EPA (US Environmental Protection Agency)			TRACI	Action assessment	Impact assessment	Assessment of 30 indicators	Action assessment Weighting of points		Indicator assessment		Assessment of 12 indicators	Assessment of 11 indicators			EPD	
	Another	Eco-Indicator-95 Eco-Indicator-99	EDIP	EKA	Eco-Indicator-99							CML2						
DATA BASE	Own	Construction materials and solutions	Sources of energy/fuels transport	GDL products	SPOLD	KBOB 100 Construction materials	Target Finder Database	Pamplets ECO-BKP	INIES	ESC Database	Green Building Database	Materials & components	Ecoinvent 2007	Simple materials and compounds	SIRADOS	EMMA & BHP	BEDEC	
Construction materials	Others		Materiales construcción.	Construction materials						Construction materials and elements			Oekoinventare Switzerland	ECOINVENT Ökoinventare Baustoff				
SCORING SYSTEM			Personal equivalentPE	Mean environmental profile	Score from 1 to 100 points	UBP. Ecopints		Environmental profil	All-round environmental profil			Ecopoints graphs			Ecopoints			

Table 9. Comparison of the environmental indicators considered by CEN and the environmental indicators considered by the BSIS(Building Sustainability Indicator Systems).

Environmental indicators suggested by CEN/TC 350		Athena Impact Estimator	Beat 2002	Be Cost	BEES	Eco Bat	Eco Calculator	Eco Effect	Eco Quantum	Eco Soft	Ener BuiLCA	ENVEST	EQUER	LCAid	LEGEP	LISA	TCQ 2000
Indicators describing environmental impacts	Global Warming Potential (GWP), kg.Eq.CO2	1	1		1	1	1	1	1	1	1	1	1	1			1
	Stratospheric ozone depletion potential (ODP)	1	1	1	1			1				1	1	1	1		
	Acidification potential, kg SO2 eq.	1	1		1	1		1		1		1	1	1	1		
	Eutrophication potential, kg PO4 eq.	1	1	1				1		1		1	1	1		1	
	Formation potential of tropospheric ozone,POCP kg Eq C2H4	1	1		1	1		1		1		1			1		
	Abiotic depletion potential for non-fossil resources, ADP-elements																
	Abiotic depletion potential for fossil resources, ADP-fossil fuels																
Indicators describing resources use	Use of renewable primary energyexcluding renovable primary energy resources used as raw materials ,PERE. MJ, net calorific value																
	Use of renewable primary energy resources used as raw materials ,PERM. MJ, net calorific value																
	Total use of renewable primary energy resources ,PERT. MJ, net calorific value																
	Use of non-renewable primary energy excluding no-renewable primary energy resources used as raw materials ,PENRE																
	Use of non-renewable primary energy resources used as raw materials ,PENRM																
	Total use of non-renewable primary energy resources ,PENRT. M.J, net calorific value	1				1	1		1	1	1		1	1			1
	Use of secondary materials kg		1		1			1	1			1					1
	Use of renewable secondary fuels, RSFS, MJ, net calorific value																
	Use of non renewable secondary fuels, RSF MJ, net calorific value		1		1	1	1	1					1				
	Use of fresh water, m3				1	1	1		1				1				1
Indicators describing complementary environmental information	Hazardous waste, kg																1
	Non-hazardous waste, kg		1			1											1
	Radioactive waste disposed (total low, intermediate and high level waste), RWD, kg							1				1					1
Total no. of coincidences		6	8	2	7	7	4	8	4	5	2	7	7	5	3	1	7

Environmental Assessment Method), which continues to be a national reference with more than 250,000 certificates. BREEAM has been adapted in Commonwealth countries (Green Leaf in Canada and Ireland, HK BEAM in Hong Kong, GreenStar in Australia and New Zealand, etc.), among others (BREEAM ES in Spain, BREEAM Gulf in the Persian Golf, etc.) (22).

In 1998, and based on BRE originally, the USGBC (United States Green Building Council) (23) launched a preliminary version of LEEDin the USA and adapted it as a commercial product in 2000. Later other reference methods appeared, supported by IISBE (International Initiative on Sustainable Built Environment) (24), on a more local scale and with a weaker impact on the real-estate market. The most outstanding ones are CASBEE in Japan, HQE in France (25, 26, 27), ITACA in Italy, MINERGIE in Swizerland, DGNB in Germany, NABERS in Australia, and VERDE in Spain backed by GBC (the Green Building Council, Spain) (28). Generally speaking, these methodologies are constantly being developed and adapted to new building developments and new technologies.

The 11 most representative sustainable assessment systems have been selected to now be applied to define their basic characteristics and to establish a comparative frame with them all. These systems can be grouped into three types according to the assessment method they employ (29):

Those based on assessing actions (Checklists), established with credits associated with points according to the relevance of the impacts related with the credit. This group comprises the systems LEED, BREEAM and DGNB.

Those based on impact assessments by analysing impacts by a cost-benefit analysis (CBA), such as CASBEE.

Those based on the assessment of the reduction of impacts by applying sustainability measures in the complete life cycle, such as: HQE (France), ITACA (Italy) and VERDE (Spain). LEED and HQE certifications recognise the life-cycle analysis, while other such as BREEAM opts for an overall cost approach Table 12 provides a comparative analysis to indicate, among other aspects, the origin, scope and extension, uses of buildings and assessment phases, employed methodology

Table 10. Comparison of the social indicators considered by CEN and the social indicators considered by the BSIS (Building Sustainability Indicator Systems).

Social Indicators suggested by CEN/TC 350		Athena Impact Estimator	Beat 2002	BeCost	BEES	EcoBat	EcoCalculator	Eco Effect	Eco Quantum	EcoSoft	Ener BuiLca	ENVEST2	EQUER	LCAid	LEGE	LISA	TCQ 2000
Accessibility	Accessibility																
Adaptability	For people with specific needs																
	To technical changes																
	To use changes																
Health and comfort	Sound characteristics																
	Quality of indoor air																
	Visual comfort																
	Thermal comfort											1	1				
	Water quality							1									
	Electromagnetic characteristics																
	Spatial characteristics												1				
Burdens on neighbours	Noise				1								1				
	Emissions to the atmosphere, land, water	1						1	1	1		1				1	
	Glare and overshading																
	Impacts and vibrations																
	Effects of wind																
Maintenance	Maintenance operations (health and confor)	1											1				
Security	Resistance to climate change																
	Resistence to accidental situations												1				
	Security against vandalism and intruders																
	Security against interruptions in supplies																
	Security against interruptions in supplies																
Origin of materials and services	Responsible and traceable origin of assets and services																
Implication of stakeholders	Opportunities for the stakeholders to participate in decision-making processes																
Total no. of coincidences		2	0	0	1	0	0	2	1	1	0	2	4	0	1	1	0

and assessed criteria. LEVEL is a new voluntary European framework developed by the European Commission, as a common EU framework for the sustainability that provides a set of indicators and common metrics for measuring the environmental performance of buildings along their life cycle (30).

As can be seen in Table 12, depending on the building type, the uses that can be assessed by 11 analysed systems are the collective residential type, offices and teaching equipment. With offices and education centres, only five systems have a specific assessment scheme that considers the characteristic aspects of these types.

Such a lack of systems that adapt to building types is a generalised matter in most methods which, despite being able to certify many kinds of uses, do not present assessment schemes that provide details of specific matters in each one, but do so with a common scheme. The most outstanding example of this is the MINERGIE system or the Canadian one, GREENGLOBES, where seven of the eight types that it certifies share the same scheme. HQE™ addresses to non-residential and residential buildings, and detached houses. Furthermore, a specific scheme for the management system of urban planning and development projects is also available.

In order to apply these systems to existing buildings, the 11 analysed systems assess new buildings and 10 of them analyse renovations. VERDE only offers a renovation assessment scheme for homes. HQE applies to residential, commercial, administrative and service buildings, whether in construction, refurbishment or in operation.

Regarding the possibility of obtaining results in the initial design phase, generally all the systems cover the first assessment in the design phase and in a later phase once the building has been constructed. Other building phases, like the operations and maintenance that buildings require throughout their life cycle or at the end of their lifespan, including demolition, are not included in 50% of the systems.

Table 12 shows that except for the MINERGIE system, which has its own standards, and CASBEE, which is based on eco-efficiency indicators, all the other procedures employ an impact assessment system by means of sustainability indicators divided into various categories.

BREEAM and GREENSTAR distribute the indicators into 10 and 9 categories, respectively, LEED and GREENGLOBES divide them into 7. In HQE, the environmental performance requirements are organised into four topics that together in-

Table 11. Comparison of the economic indicators considered by CEN and the Economic indicators considered by the BSIS (Building Sustainability Indicator Systems).

Economic Indicators suggested by CEN/TC 350		Athena Impact Estimator	Beat 2002	BeCost	BEES	Eco-Bat	Eco Calculator	Eco Effect	Eco Quantum	EcoSoft	Ener BuiLca	ENVEST 2	EQUER	LCAid	LEGEP	LISA	TCQ 2000
Cost	Investment cost	0		1	1											1	
	Explotation and maintenance cost			1	1							1			1	1	
	Demolition and waste management cost			1	1							1				1	
Financial value	Investment fiancial cost											1					
	Explotation and maintenance 1 cost											1					
	Demolition and waste management cost			1								1					
Ratio between market value and capital cost	Ratio between market value and capital cost at the building work completion																
Verification of value versus future stability	Value versus future stability of economic value of clasification of ownership																
Economic risk	Stability of economic value by undertaking analysis of financial scenarios																
External costs	External costs																
Results economic aspects	Energy efficiency level (relative to a high energy cost)																
	Adaptability to users' requirements																
	Intrinsic risks in localisation																
	Accessibility																
	Spatial efficiency																
Total number of coincidences		0	0	4	3	0	0	0	0	0	0	5	0	0	1	3	0

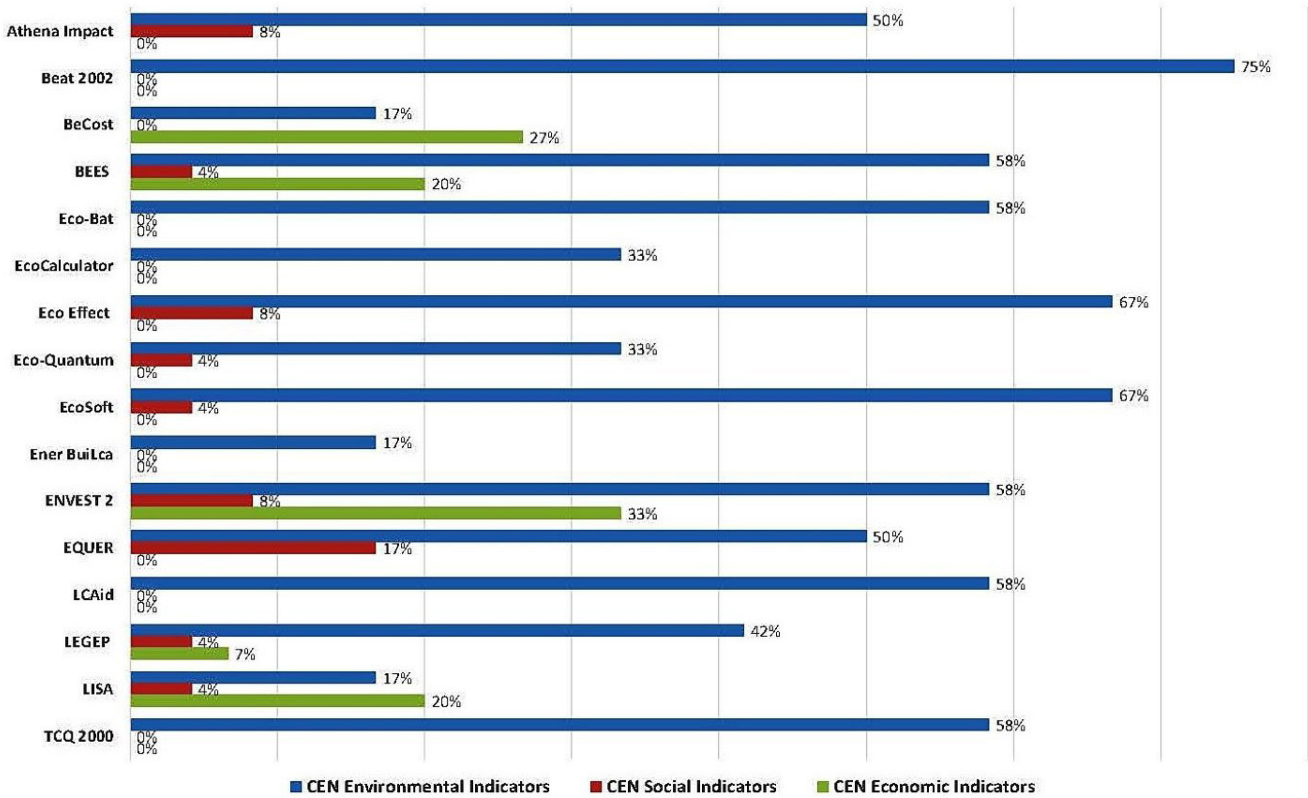

Figure 3. Proportion of the indicators suggested by CEN considered by the BSIS.

Table 12. A comparison of the international sustainable certification systems for building (source: the authors, adapted on Rojo, 2014) (31).

		LEED+	BREEAM	VERDE	CASBEE	GREEN STAR	GREEN GLOBES	MINERGIE	HQE	DGNB	ITACA
ORIGIN		1998 USA	1990 UK	2010 SPAIN	2001 JAPAN	2003 AUSTRALIA	2001 CANADA	2006 SWITZERLAND	2005 FRANCE	2008 GERMANY	2004 ITALY
ORGANISATION		GBC USA	BRE Global	GBC Spain	JSBC Japan	GBC Australia	ECD BOMA Canada	MINERGIE Association	HQE / AFNOR	GBC Germany	ITACA Institute
ALCANCE / EXTENSIÓN											
	No. countries	+ 120	40	1	2	2	2	8	11	18	1
USES	Housing estate	LEED ND	BREEAM COMMUNITIES		CASBEE URBAN DEVELOPMENT				HQE AMÉNAGEMENT	DGNB URBAN DISTRICTS	
USES	Blocks of homes	LEED HOMES	BREEAM NC MULTI-RESIDENTIAL	NE RESIDENTIAL & OFFICES	CASBEE HOMES	GREEN STAR MULTI RESIDENTIAL	GREENGLOBES NC	MINERGIE-ECO	NF HQE LOGEMENT	DGNB RESIDENTIAL	RESIDENZIALE
USES	Single-family homes	LEED HOMES	BREEAM ECOHOMES	NE SINGLE-FAMILY	CASBEE HOMES	GREEN STAR UNI RESIDENTIAL		MINERGIE-ECO	NF HQE MAISON INDIVIDUELLE	DGNB SMALL RESID.	
USES	Hotels	LEED NC	BREEAM NC OTHER BUILDINGS	NE EQUIPAMENT	CASBEE NC		GREENGLOBES NC		NF HQE. TERTIAIRES	DGNB HOTELS	
USES	Health	LEED NC HEALTHCARE	BREEAM NC HEALTHCARE	NE EQUIPMENT	CASBEE NC	GREEN STAR HEALTHCARE	GREENGLOBES HEALTHCARE		NF HQE TERTIAIRES	DGNB HOSPITALS	
USES	Schools	LEED NC SCHOOLS	BREEAM NC EDUCATION	NE EQUIPMENT	CASBEE NC	GREEN STAR EDUCATION	GREENGLOBES NC	MINERGIE-ECO	NF HQE TERTIAIRES	DGNB EDUCATIONAL	SCOLASTICI
USES	Offices	LEED NC	BREEAM NC OFFICES	NE RESIDENTIAL & OFFICES	CASBEE NC	GREEN STAR OFFICE	GREENGLOBES NC	MINERGIE-ECO	NF HQE TERTIAIRES	DGNB OFFICE	UFFICI
USES	Shops/Stores	LEED CS-CORE&SHELL LEED CI- INTERIORS	BREEAM NC RETAIL	NE EQUIPMENT	CASBEE MARKET	GREEN STAR RETAIL	GREENGLOBES NC		NF HQE TERTIAIRES	DGNB RETAIL	COMMERCIALI
USES	Industrial	LEED NC	BREEAM NC INDUSTRIAL		CASBEE NC		GREENGLOBES NC			DGNB INDUSTRIAL	INDUSTRIALI
USES	Specialised		BREEAM NC OTHER BUILDINGS		CASBEE NC	GREEN STAR PUBLIC BUILDING	GREENGLOBES NC		EQUIP. SPORTIFS	ASSEMBLY MIXED USE	
ASSESSABLE PHASES	Design	X	X	X		X	X	X	X	X	X
ASSESSABLE PHASES	Construction	X	X	X	X	X	X	X	X	X	X
ASSESSABLE PHASES	Use	X	X	X		X	X	X		X	
ASSESSABLE PHASES	Maintenance	X	X		X		X			X	
STATUS	New buildings	X	X	X	X		X			X	
STATUS	Existing buildings	X	X	X	X		X	X		X	X
ASSESSMENT METHOD											
	Assessment	Action assessment	Action assessment Weighting of points	Impact assessment	Energy efficiency	Action assessment Weighting of points	Impact assessment and others	Conditions assessment	Valoración actuaciones Ponderación de puntos	Does not assess individual measures	Action assessment Weighting of points
	Database	NO	NO	YES	YES	YES	YES	NO	YES	YES	YES
	Database	Guía referencia	Green Book Live	HADES	JSB Database	CIR Rulings Database	Target Finder Database	Pamplets ECO-BKP	INIES	ESC Database	Green Building Database
SCORING SYSTEM	Label										
SCORING SYSTEM	Assessment scale	CERTIFICATE >40 SILVER >50 GOLD >60 PLATINUM >80 Max. score 110	FULFILS >30 GOOD >45 VERY GOOD >70 EXTREMELY GOOD >85 Max. score 100	0 SHEETS 0.0 - 0.5 1 SHEET 0.5 - 1.5 2 SHEETS 1.5 - 2.5 3 SHEETS 2.5 - 3.5 4 SHEETS 3.5 - 4.5 5 SHEETS 1.5 - 5.0	CLASS C CLASS B- CLASS B+ CLASS A CLASS S Low score Excellent	1 STAR >10 2 STAR >20 3 STAR >30 4 STAR >45 5 STAR Excel. >60 6 STAR Leader >75	1 GLOBE V >35% 2 GLOBES V >55% 3 GLOBES V >70% 4 GLOBES V >85% Max. score. 1000		BASIC GOOD VERY GOOD	BRONZE >50% SILVER >60% GOLD >80%	NEGATIVE (-1) GOOD (0) ENOUGH (1,2,3) VERY GOOD (-4,5)

clude 14 categories. Moreover, the HQE certification is different due to the introduction of requirements concerning comfort and health. LEVEL guides users from an initial focus on individual aspects of building performance towards a more holistic perspective. It consists of eight core indicators, complemented by six life cycle tools which include the option to make a full Life Cycle Assessment (LCA).

Tables 13, 14 and 15 and Figure 4 compare the CEN indicators considered by the Comprehensive Building Environmental Assessment (CBEA) systems.

3. DISCUSSION AND CONCLUSIONS

According to Tables 13, 14 and 15 and to Figure 4, of all the systems that certify a building's sustainability, LEVEL,LEED, BREEAM, VERDE, HQE and DGNB are the most complete systems as they have the most coincidences as regards the indicators set out by the CEN/TC350 . LEED, HQE and LEVEL covers all the environmental indicators whereas BREEAM covers the 65%.

Most coincidences come about when using raw materials. This indicator is considered by all the systems according to the categories 'Indoor air quality', 'Energy', along with the categories 'Energy use' and 'Land ecology', which are indicators included in 8 9 of the 11systems. Aspects like 'Waste' are dealt with by only half the systems.

Themes and categories are not accurate, are heterogeneous, and have fuzzy limits. For example, pollution indicators are mixed in the energy or indoor air quality categories.

BREEAM , HQE and DGNB are those with more social indicators (32%), followed by VERDE, LEVEL and LEED (28%). Security category is not implemented in any of the analysed systems. LEVEL uses the 67% of the economic indicators, followed by DGNB with the 40%. In the opposite, GBTool, GREEN STAR and GREEN GLOBES do not include any economic indicator. However, like other systems, they will have to cover socio-economic aspects more profoundly.

From the conducted study, it can be observed that of the three sustainable development pillars, all the analysed systems focus basically on weighting environmental criteria and consider to a much lesser extent the social and economic aspects.

About 97% of the social and economic indicators remain unconsidered by the studied data-driven LCIA methods, and about 64 % of them are unconsidered by the studied data-driven BSIS. Effort-driven assessment tools have a higher consideration of these social and economic aspects, as this type of assessment has a more comprehensive nature. However, there is still about half of the proposed economic indicators by the CEN unconsidered by the CBEA methods. Only one of the studied assessment tools consider accessibility criteria, which is a relevant social sustainability aspect. Adaptability, security and implication of stakeholders are other social types of indicators with a low level of development in the studied tools. Regarding the economic types of indicators suggested by the CEN/TC 350, it is worth noticing that only LEVEL includes criteria to assess the ratio between market value and capital cost, the value versus future stability, the economic risk, or the external costs.

Table 13. Comparison of the environmental indicators considered by CEN and the environmental indicators considered by the CBEA (Comprehensive Building Environmental Assessment) systems.

Environmental indicators suggested by CEN/TC 350		LEED	BREEAM	VERDE	CASBEE	GBTool	GREEN STAR	GREEN GLOBES	MINERGIE	HQE	DGNB	ITACA	LEVEL
Indicators describing environmental impacts	Global Warming Potential (GWP), kg.Eq.CO_2	1	1	1	1	1		1	1	1	1	1	1
	Stratospheric ozone depletion potential (ODP)	1	1			1				1	1		1
	Acidification potential, kg SO_2 eq.	1	1			1				1			1
	Eutrophication potential, kg PO_4 eq.	1	1			1				1			1
	Formation potential of tropospheric ozone,POCP kg Eq C_2H_4	1	1							1			1
	Abiotic depletion potential for non-fossil resources, ADP-elements	1								1			1
	Abiotic depletion potential for fossil resources, ADP-fossil fuels	1								1			1
Indicators describing resources use	Use of renewable primary energy excluding renovable primary energy resources used as raw materials ,PERE. MJ, net calorific value	1								1			1
	Use of renewable primary energy resources used as raw materials ,PERM. MJ, net calorific value	1								1			1
	Total use of renewable primary energy resources ,PERT. MJ, net calorific value	1								1			1
	Use of non-renewable primary energy excluding no-renewable primary energy resources used as raw materials ,PENRE	1	1	1	1		1	1	1	1		1	1
	Use of non-renewable primary energy resources used as raw materials ,PENRM	1	1							1			1
	Total use of non-renewable primary energy resources ,PENRT. M.J, net calorific value	1	1							1			1
	Use of secondary materials kg	1	1	1	1	1	1	1	1	1	1	1	1
	Use of renewable secondary fuels, RSFS, MJ, net calorific value	1	1	1		1		1		1			1
	Use of non renewable secondary fuels, RSF MJ, net calorific value	1								1			1
	Use of fresh water, m^3	1	1	1	1		1	1	1	1	1		1
Indicators describing complementary environmental information	Hazardous waste, kg	1	1						1	1			1
	Non-hazardous waste, kg	1								1			1
	Radioactive waste, kg	1	1							1			1
Total no. of coincidences		20	13	5	4	6	3	5	5	20	4	3	20
		100%	65%	25%	20%	30%	15%	25%	25%	100%	20%	15%	100%

Table 14. Comparison of the social indicators considered by CEN and the social indicators considered by the CBEA (Comprehensive Building Environmental Assessment) systems.

Social Indicators suggested by CEN/TC 350		LEED	BREEAM	VERDE	CASBEE	GBTool	GREEN STAR	GREEN GLOBES	MINERGIE	HQE	DGNB	ITACA	LEVEL
Accessibility	Accessibility												
Adaptability	For people with specific needs												
	To technical changes										1		1
	To use changes												1
Health and comfort	To use changes												1
	Sound characteristics	1	1	1									
	Quality of indoor air	1	1	1	1	1	1	1	1	1	1	1	1
	Visual comfort	1	1	1	1					1	1	1	
	Thermal comfort	1	1	1	1					1	1		1
	Water quality									1			
	Electromagnetic characteristics												
Burdens on neighbours	Spatial characteristics												
	Noise		1	1	1					1	1		
	Emissions to the atmosphere, land, water	1	1	1				1		1		1	1
	Glare and overshading												
	Impacts and vibrations												
	Effects of wind												
Maintenance	Maintenance operations (health and confor)	1	1		1			1	1	1	1		1
Security	Resistance to climate change												
	Resistence to accidental situations				1					1	1		
	Security against vandalism and intruders												
	Security against interruptions in supplies												
Origin of materials and services	Security against interruptions in supplies												
Implication of stakeholders	Responsible and traceable origin of assets and services	1	1	1								1	
	Opportunities for the stakeholders to participate in decision-making processes										1		
Total no. of coincidences		7	8	7	6	1	1	3	2	8	8	4	7
		28%	32%	28%	24%	4%	4%	12%	8%	32%	32%	16%	28%

Table 15. Comparison of the economic indicators considered by CEN and the economic indicators considered by the CBEA (Comprehensive Building Environmental Assessment) systems.

Economic Indicators suggested by CEN/TC 350		LEED	BREEAM	VERDE	CASBEE	GBTool	GREEN STAR	GREEN GLOBES	MINERGIE	1%	DGNB	ITACA	LEVEL
Cost	Investment cost	1		1							1		1
	Explotation and maintenance cost		1	1	1						1		1
Financial value	Demolition and waste management cost										1		
	Investment fiancial cost	1		1									1
	Explotation and maintenance cost		1								1		1
Ratio between market value and capital cost	Demolition and waste management cost										1		1
Verification of value versus future stability	Ratio between market value and capital cost at the building work completion												1
Economic risk	Value versus future stability of economic value of clasification of ownership												1
External costs	Stability of economic value by undertaking analysis of financial scenarios												
Results economic aspects	External costs												1
	Energy efficiency level (relative to a high energy cost)	1	1	1	1				1	1		1	1
	Adaptability to users' requirements										1		1
	Intrinsic risks in localisation												
	Accessibility		1										
	Spatial efficiency												
Total number of coincidences		3	4	4	2	0	0	0	1	1	6	1	10
		20%	27%	27%	13%	0%	0%	0%	7%	7%	40%	7%	67%

With regard to the environmental pillar, most data-driven assessment methods consider criteria that describe environmental impacts, such as the global warming potential, the stratospheric ozone layer depletion potential, the acidification potential, the eutrophication potential and ecotoxicity. For emissions, a consensus has been reached by the implied agents, considering the global warming potential as well as emissions of other gases (sulphur oxides, SOx, nitrogen oxides, NOx, methane, CH4, etc.) as the most representative indicator when it comes to assessing the environmental qual-

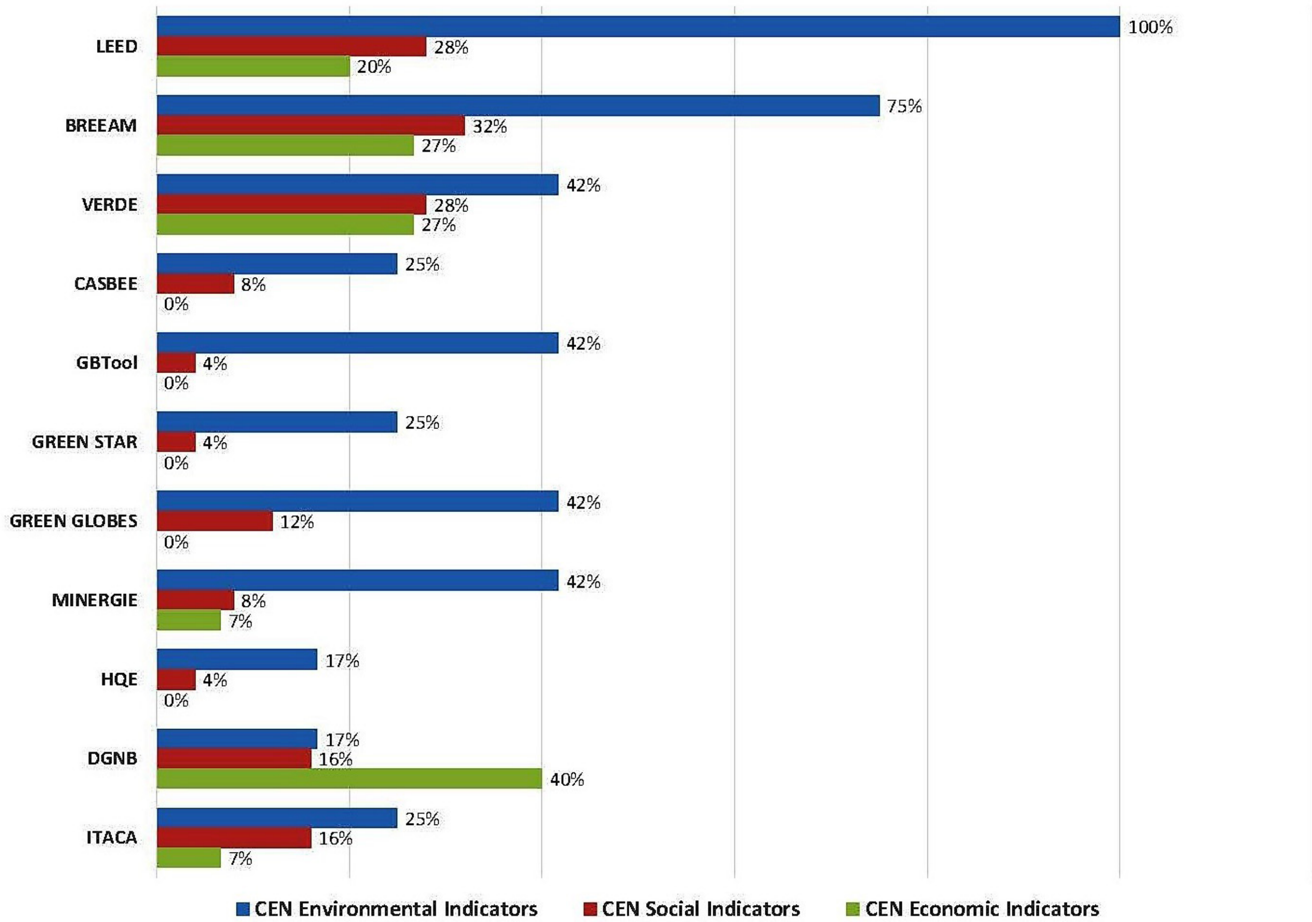

Figure 4. Proportion of the indicators suggested by CEN considered by the CBEA.

ity of buildings. However, environmental impacts indicators are not so developed in the effort-driven tools, and therefore there is an opportunity of integration of the two types of tools in this regard.

It must be noticed that the less developed type of environmental indicator, in both data-driven and effort-driven sustainability assessment tools, is the one describing complementary environmental information related to waste.

In conclusion, social and economic indicators require further development in the existing sustainability assessment systems of buildings, and environmental indicators require improvement, especially regarding waste criteria, and the integration of indicators describing environmental impacts –well developed in data-driven methods– into effort-driven methods.

ACKNOWLEDGEMENTS

This work has been carried out as part of the research project 'Integrated design protocol for social housing retrofit and urban regeneration' (BIA2013-44001-R) in the Spanish Research, Development and Innovation Programme 'Society's Challenges', funded by the Spanish Ministry of Economy and Competitiveness.

BIBLIOGRAPHY

(1) Haapio, A. & Viitaniemi, P. (2008). 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
(2) Chandratilake, S.R., & Dias, W.P.S. (2013). Sustainability rating systems for buildings: Comparisons and correlations. *Energy*, 59: 22-28. https://doi.org/10.1016/j.energy.2013.07.026
(3) Cole, R.J. (2005). Building environmental assessment methods: redefining intentions and roles. *Building Research & Information*, 33(5): 455-467. https://doi.org/10.1080/09613210500219063
(4) Nguyen, B.K. & Altan, H. (2011). Comparative review of five sustainable rating systems. *Procedia Engineering*, 21: 376-386. https://doi.org/10.1016/j.proeng.2011.11.2029
(5) Berardi, U. (2012). Sustainability assessment in the construction sector: rating systems and rated buildings. *Sustainable Development*, 20(6): 411-424. https://doi.org/10.1002/sd.532
(6) Lee, W.L. (2012). Benchmarking energy use of building environmental assessment schemes. *Energy and Buildings*, 45: 326-334. https://doi.org/10.1016/j.enbuild.2011.11.024

(7) Sharifi, A. & Murayama, A. (2013). A critical review of seven selected neighborhood sustainability assessment tools. *Environmental Impact Assessment Review*, 38: 73-87. https://doi.org/10.1016/j.eiar.2012.06.006
(8) Kajikawa, Y., Inoue, T. & Goh, T.N., (2011a). Analysis of building environment assessment frameworks and their implications for sustainability indicators. *Sustainability Science*, 6(2): 233–246. https://doi.org/10.1007/s11625-011-0131-7
(9) World Commission on Environment and Development (WCED) (1987). *Our Common Future: Report of the World Commission on Environment and Development*. Retrieved from http://www.un-documents.net/our-common-future.pdf (accessed on 6 September 2016).
(10) United Nations Environment Programme (UNEP) (2010). *Guidelines on Education Policy for Sustainable Build Environments*. Retrieved from http://wedocs.unep.org/handle/20.500.11822/7997 (accessed on 6 September 2016).
(11) Gibson, R.B. (2006). Beyond the pillars: sustainability assessment as a framework for effective integration of social, economic and ecological considerations in significant decision-making. *Journal of Environmental Assessment Policy and Management*, 8(03): 259-280. https://doi.org/10.1142/S1464333206002517
(12) Nidumolu, R., Prahalad, C.K. & Rangaswami, M.R. (2009). Why sustainability is now the key driver of innovation. *Harvard business review*, 87(9): 56-64.
(13) Gibberd, J. (2005). Assessing sustainable buildings in developing countries – the sustainable building assessment tool (SBAT) and the sustainable building lifecycle (SBL). In *Proceedings of the world sustainable building conference*. (pp. 1605–1612). Tokyo.
(14) Hikmat, H. & Nsairat, S. (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
(15) Andreas, G., Allen, J. & Farley, L. (2010, March). Towards the Development of a Rating System for Sustainable Infrastructure: A Checklist or a Decision-Making Tool? In *Proceedings of the Water Environment Federation, Cities of the Future/Urban River Restoration*. (pp. 379–391). Boston, MA, USA.
(16) Huedo, P., Mulet, E. & López-Mesa, B. (2016). A model for the sustainable selection of building envelope assemblies. *Environmental Impact Assessment Review*, 57: 63-77. PII: S0195-9255(15)00121-3. https://doi.org/10.1016/j.eiar.2015.11.005
(17) Bare, J.C., Hofstetter, P., Pennington, D.W. & Udo de Haes H.A. (2000). Midpoints versus endpoints: The sacrifices and benefits. *The International Journal of Life Cycle Assessment,* 5(6): 319–326. https://doi.org/10.1007/BF02978665
(18) Pieri, C., Dumanski, J., Hamblin A. & Young, A. (1995). *Indicadores de Calidad de la tierra. Documentos de Discusión del Banco Mundial*. Washington, DC: El Banco Mundial.
(19) Huedo, P. & Lopez-Mesa, B. (2011). Revisión de herramientas de asistencia en la selección de soluciones constructivas. *Informes de la Construcción*, 65(529): 77-88. https://doi.org/10.3989/ic.11.048
(20) Kajikawa, Y., Inoue, T. & Goh, T.N., (2011b). Analysis of building environment assessment frameworks and their implications for sustainability indicators. *Sustainability Science*, 6(2): 233–246. https://doi.org/10.1007/s11625-011-0131-7
(21) Castro-Lacouture, D., Sefair, J.A., Flórez, L. & Medaglia, A.L. (2009). Optimization model for the selection of materials using a LEED-based green building rating system in Colombia. *Building and Environment*, 44(6): 1162-1170. https://doi.org/10.1016/j.buildenv.2008.08.009
(22) France GBC & Alto Ingenierie (2015). *International environmental certifications for the design and construction of non-residential buildings. The positioning of HQE certification relative to BREEAM and LEED.*
(23) *USGBC Green Building Council*. Retrieved from http://www.usgbc.org/?CategoryID=19 [accessed 21.04.14].
(24) Mallawarachchi, H., De Silva, L., Rameezdeen, R. (2013). Green buildings, resilience ability and the challenge of disaster risk. *International Conference on Building Resilience*, September 2013, Ahungalla, Sri Lanka. Retrieved from https://www.researchgate.net/publication/277892802_Green_buildings_resilience_ability_and_the_challenge_of_disaster_risk [accessed Mar 04 2018].
(25) Bernardi, E., Carlucci, S., Cornaro, C., Bohne , R.A. (2017). Analysis of the Most Adopted Rating Systems for Assessing the Environmental Impact of Buildings. *Sustainability*, 9(7): 1226. https://doi.org/10.3390/su9071226
(26) HQE. Haute Qualitè Environnementale (2017). Retrieved from http://www.behqe.com [accessed on 26 June 2017].
(27) Cerway. HQE™ Management System for Urban Planning Projects. Requirements Scheme for the Management System of Urban Planning and Development Projects—HQE™ Certified by Cerway; Cerway: Paris, France, 2014. [Google Scholar]
(28) Garcia, J. & Macías, M. (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
(29) Rodriguez-López, F. & Fernández-Sánchez, G. (2009). Sostenibilidad en los proyectos de construcción. Análisis de un edificio frente a dos herramientas de evaluación sostenible. In *Proceedings of the XII Congreso de Ingeniería de Proyectos AEIPRO*. Badajoz.
(30) Dodd, N., Cordella, M., Traverso, M., Donatello, S. (2017). *Level(s) - A common EU framework of core sustainability indicators for office and residential buildings*. European Commission, JRC technical reports.
(31) Rojo, M. (2014). Estudio de la implementación de sistemas de certificación sostenible en edificación. Aplicación de LEED en el Colegio CEIP PIO XII, de Onda Castellón. (Master’s Degree Project). Castellón: Universitat Jaume I.

* * *