Sustainable Construction Key Indicators

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ABSTRACT: Sustainable building is a concept that began its development nearly two decades ago. With sustainable buildings, it is intended to establish building practices that allow minimizing the buildings impacts, build and manage buildings with an adequate balance between environment, society and economy.
However, besides the importance of this concept, its broader implementation is not yet a reality. Several studies have been developed with the goal of understand the reason of these weak implementation. They have concluded that one of the main reasons is because the building stakeholders still consider sustainable practices more expensive, although several studies state the contrary. In order to potentiate the implementation of these practices, a work will be developed in order to perform a cost-benefit analysis of sustainable construction solutions.
In order to perform this work, it was necessary, in an initial stage, to define the key indicators that should be considered in order to assess the main aspects of sustainable construction. This paper intends to present the analysis that was performed in order to select these indicators.

1 INTRODUCTION

The buildings environmental impact has been a growing concern across the last decades. The relation between the planet environmental problems and the building sector is proven and accepted. Thus, there is an increasing demand for environmental friendly construction practices in order to minimize the building sector negative impacts (Cole 1999).

Due to these concerns, the necessity to develop a set of metrics in order to evaluate the buildings environmental impacts has emerged. Consequently, it was also necessary to establish benchmarks to these metrics. Thus, several entities have developed several sustainable building assessment methodologies. These methodologies have defined reference practices and have contributed to the implementation of sustainable development in the building sector (Ding 2008). These systems also allow to assess and monitor the buildings performance and to disseminate the importance of adopting sustainable practices.

In their beginning, these methodologies focused only on environmental indicators. However, with time, it was possible to understand the importance of the social and economic issues, regarding the buildings sustainability. Therefore, social and economic indicators began to be considered in these methodologies. Generally, building sustainability assessment (BSA) tools evaluate the buildings sustainability level through the aggregation of the building performance in a group of sustainability indicators.

The first developed BSA tool was BREEAM - *Building Research Establishment Environmental Assessment Methodology* (BREEAM 2012), in 1990. After this, other BSA tools were developed such as: LEED - *Leadership in energy and environmental design* (LEED 2013), developed in the United States of America, SBTool – Sustainable Building Tool (iiSBE 2012) developed by *International Initiative for a Sustainable Built Environment* (iiSBE), CASBEE - *Comprehen-*

sive Assessment System for Building Environmental Efficiency (CASBEE 2012) developed in Japan, among many other.

Each one of these tools defines their own set of sustainability indicators depending on the sociocultural environment since the importance of each indicator is different in different contexts. Therefore, several studies (Alwaer and Clements-Croome 2010, Bragança, Mateus et al. 2010, Chen, Okudan et al. 2010) were developed with the goal of develop a specific set of indicators applied to a specific location or type of building. However, these specificities make each tool very different from each other. These differences also led to a problem, since they make the comparison of results obtained through different methodologies difficult (Huovila, 2012).

In order to overcome these constraints, the two main standardization organizations, European Normalization Committee (CEN) and the International Standardization Organization (ISO) have been developed work with the goal of standardize the sustainable construction assessment (Mateus and Bragança 2011, Alyami and Rezgui 2012).

The goal of most BSA tools is mostly commercial. However, alongside with these tools, some initiatives have been developed by non-profit organizations (iiSBE, SB Challenge, SB Alliance), and through financed projects (LEnSE, SuPerBuildings, OPEN HOUSE), with the goal of defining and developing a set of sustainable buildings key indicators. These initiatives have taken into consideration the developments of several national and international BSA tools, the standards published by ISO and CEN as well as the opinion of some recognized European building construction stakeholders.

In order to study the sustainable construction it was very important to select the proper indicators. These indicators should include the main building impacts and assess the particular aspects of the socioeconomic context.

2 EUROPEAN PROJECTS

In order to define the sustainable building key indicators, four European initiatives have been analysed, the Sustainable Building Challenge 2011 and 2013 key indicators, the Sustainable Building Alliance, the SuPerBuildings and the OPEN HOUSE project. These initiatives are chosen because they are European initiatives that have performed recent work with the goal of define sustainable construction key indicators. In the next sections, a brief description of each of these initiatives is presented.

2.1 *SB Challenge - Sustainable Building Challenge*

The goal of the Sustainable Building Challenge (SB Challenge) process is to analyse and present innovative sustainable buildings techniques and concepts. It is organized by *International Initiative for a Sustainable Built Environment* (iiSBE) and has been an important part of *World Sustainable Building Conferences* the since 1998 (SBChallenge11 2011).

The participants of each SB Challenge edition identify buildings representative of their regions and assess their performance through a common BSA tool. In the first editions, the chosen tool was GBTool (the first version of SBTool). However, in the most recent editions, each participant is allowed to use any recognized assessment tool, as long as a set of key indicators is assessed.

Nevertheless, more focus has been given to the key indicators analysis, since it was very difficult to compare results obtained through different tools. Thus, one of the main aspects of this process is to define a set of metrics valid across different regions (SB Conferences 2013). The key indicators used in each edition were defined by iiSBE. This initiative was constituted by a broad range of members from different nationalities. These members are involved both in professional and academic building sector world. The multidisciplinarity of members ensures that the key indicators chosen were adequate to apply in different contexts.

2.2 *SB Alliance - Sustainable Building Alliance*

The Sustainable Building Alliance (SB Alliance) is a non-profit organization with the goal of createing an uniform language between the different BSA tools. In order to achieve this goal, SB alliance intends to define a set of sustainable building key indicators (Freyd 2012). This work has been performed by professional from several recognized institutions.

In order to select the indicators, this initiative have analysed several available BSA tools and their indicators as well as the released standards within the sustainability assessment theme. As expected, a very long list of indicators has been obtained in the analysis. The selection of the key indicators was performed through the analysis of each indicators and accordingly to the opinion of the SB Alliance members.

2.3 *SuPerBuildings - Sustainability and Performance assessment and benchmarking of Buildings*

The SuPerBuildings project (SuPerBuildings 2012) is an European project financed by the Seven Framework Programme (7FP). This project has selected and developed a set of key sustainability indicators for buildings. Besides, this project has also developed its own assessment methods and benchmarks. The project was developed considering new and existing buildings, different building types, different building stages and different national and local requirements. SuPerBuildings also intended to establish principles in order to help teams that want to develop new BSA tools (Huovila 2012).

The key indicators selection was performed taken into consideration the building life cycle. Both qualitative and quantitative indicators were chosen. However, regarding the qualitative ones, an additional effort was made in order to assure their reliability.

The key indicators selection was made with the consideration of the standards, initiatives and methodologies presented in Table 1.

Table 1. Initiatives, standards and BSA tools analysed by SuPerBuilings (Huovila 2012).

European And International Initiatives And Standardization Activities	National Sustainability Assessment Tools	
CEN TC 350	BREEAM & Code for Sustainable Homes (U. K.)	LEED (U.S.A.)
ISO TC59 SC17	DGNB (Germany)	SBtool CZ (Czech REpublic)
Sustainable Building Alliance (SBA)	PromisE (Finland)	Klima:aktiv Gebäude-standard (Austria)
UNEP SBCI	HQE (France)	TQB (Austria)
LEnSE	Valideo (Belgium)	GPR Gebouw (Netherlands)
Perfection	CASBEE (Japan)	

2.4 *OPEN HOUSE - Benchmarking and mainstreaming building sustainability in the UE based on transparency and openness from model to implementation*

The OPEN HOUSE project is also an European project financed by the Seven Framework Programme (7FP). The goal of this project was to develop and implement an European building sustainability assessment methodology. In order to achieve that goal, the project team encompasses different stakeholder across the Europe (OPEN HOUSE 2010).

The OPEN HOUSE methodology is based in the ISO and CEN standards and in the existent BSA tools, assessing the building life cycle.

The methodology was developed to be applied to office buildings and includes environment, social and economic indicators. Additionally OPEN HOUSE includes another three transversal aspects, namely, technical characteristics, process quality and location (Figure 1). However, the last category is extra since their evaluation object goes beyond the boundaries of the system (building and landscaping) and cannot be influenced by design options. (Zavrl, Tomsic et al. 2010).

OPEN HOUSE have 56 indicators distributed among these six categories. Some of these 56 indicators are pointed as key indicators and their assessment allow to obtain an initial idea about the building sustainability performance.

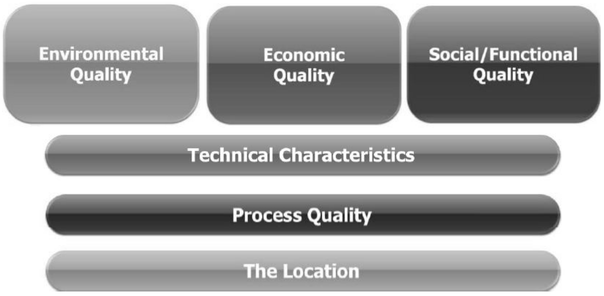

Figure 1. OPEN HOUSE categories (Zavrl, Tomsic et al. 2010).

3 EUROPEAN PROJECTS KEY INDICATORS

In order to select the key indicators that will be used in this study, the indicators selected by the four initiatives presented were analysed.

As exposed before, each one of the initiatives presented intended to select building sustainability key indicators. Therefore, the selection of a certain indicator by the majority of these initiates is a strong indication of its importance.

In Table 2 the indicators selected by the initiatives analysed were presented. Regarding the OPEN HOUSE methodology, only the main indicators were presented.

In this table, the indicators were grouped into sustainability categories. These categories were chosen accordingly to the findings of the initiatives.

Table 2 (part 1). Indicators selected by the different initiatives.

Indicators	SB Challenge11	SB Challenge14	SB Alliance	SuPerBuildings	OPEN HOUSE
Location					
Public transportation system	X	X			X
Proximity to amenities	X			X	
Site risk					X
Energy and emissions					
Building materials embodied energy	X				
Non-renewable primary energy	X	X	X	X	X
Renewable energy	X	X			X
Green House Gases Emissions	X	X	X	X	
Materials and waste					
Global warming potential					X
Ozone depletion potential					X
Acidification potential					X
Eutrophication potential					X
Photochemical oxidation potential					X
Reused materials	X				
Renewable materials	X				
Waste production			X	X (RCD)	X
Materials responsible source					X
Water					
Water consumption	X	X	X	X)	X
Potable water usage	X	X			
Water pollution (leaching)				X	
Land use and biodiversity					
Soil sealing				X	
Undisturbed areas contamination					X
Users health and comfort					
Lightning		X	X (i.d.)	X	X

Table 2 (part 2). Indicators selected by the different initiatives.

Thermal comfort		X	X	X	X
Indoor air quality	X	X	X	X	X
Acoustic comfort			X (i.d.)	X	X
Users comfort control					X
Electromagnetic pollution					X
Free barriers accessibility					X
Cyclists comfort					X
Society / culture					
Public accessibility					X
Esthetical quality				X	
Historical heritage				X	
Service quality					
Building envelope quality					X
Conversion reliability					X
Spatial efficiency	X				X
Easiness of dismantling and recycle	X				X
Economic performance					
Life cycle costs	X		X (i.d.)	X	X
Long-term value stability				X	
Process quality					
Integrated design process				X	X
Construction process impact					X
Commissioning					X

Note: i.d. – in development

This analysis showed that despite of all efforts that have been performed regarding the harmonization of sustainable construction language, there are still significant differences between the key indicators of each initiative. However, it was possible to verify that there are some indicators that are selected by most of the initiatives.

4 KEY INDICADORS SELECTED

The total number of indicators selected by the four initiatives analysed was forty one. However, it was verified that twenty seven of these were selected only by one of the initiatives. Table 3 presents the list of indicators selected by at least three initiatives. The indicators presented in Table 3 were chosen to the study, with the exception of “Public transportation system”. This indicator will not be studied since their performance cannot be changed by design options and its assessment is beyond the building boundaries.

Table 3. Indicators selected by at least three initiatives.

INDICATOR	NUMBER OF SELECTIONS
Non-renewable primary energy	5
Water consumption	5
Indoor air quality	5
GHG emissions	4
Lightning	4
Thermal comfort	4
Life cycle costs	4
Public transportation system	3
Renewable primary energy	3
Acoustic comfort	3

As exposed, the fact that an indicator was frequently included in different BSA tools or initiatives is a good indication of its importance. However, excluding other indicators, only because they are not usually assessed can led to an exclusion of important impacts. In order to understand the importance and significance of each indicator referred in Table 2, a bibliographic revision of the correspondent impacts were performed.

Besides this analysis, the selection of indicators was performed considering the following aspects:

- All indicators with a subjective assessment were excluded;
- All indicators whose performance cannot be changed by design options or whose assessment goes beyond the building boundaries were excluded;
- All indicators whose performance was difficult to translate into economic terms were excluded.

Additionally, it was intended that the key indicators list is broad enough to include the mainly sustainable buildings impacts, but also concise enough in order to make the assessment practicable.

There are some indicators which impacts were considered important but that were not chosen to the study because the difference of costs between the different associated building practices was difficult to assess. These indicators were: soil sealing, undisturbed areas contamination, conversion reliability, easiness of dismantling and recycle and spatial efficiency.

Additionally to the indicators presented in Table , ten additional indicators were selected with less than 3 selections in the methodologies. These ten indicators were associated with two categories, materials and wastes, process quality. In order to understand the importance of these indicators, a brief bibliographic review of these two categories is presented below.

4.1 *Materials and Wastes*

The building sector is responsible for the extraction of 24% of raw materials on Earth. Additionally, the extraction, processing, transport and application of building materials are responsible for the consumption of great amounts of energy (EC, 2011). Therefore, the quantity and type of materials used in construction have a huge influence on the building environmental impacts (Krausmann et al., 2009).

The importance of these impacts in buildings sustainability assessment is undeniable. However, sometimes, these impacts were not assessed in BSA tools due to the complexity associated with their assessment. When considered, the building materials environmental impacts were assessed through a Life Cycle Analysis (LCA). LCA is a methodology that assesses the environmental impacts of a product, system or material during all of their life cycle (Rincón et al., 2013). Through an LCA it is possible to quantify the following indicators: materials embodied energy, ozone depletion potential, acidification potential, eutrophication potential and photochemical oxidation potential.

The building sector is also responsible for the production of 40% of the world solid waste (UNEP, 2011). So, the quantity of waste produced by a building both in the construction and in the operation phase is also a very important indicator in the building sustainability assessment.

4.2 *Process Quality*

The process quality category is related with the measures that could be taken for the proper development of the building construction and management process.

An emergent theme related with the sustainable buildings is the Integrated Design Process (IDP). As already stated, the sustainable construction is a broadly and multidisciplinary theme, that encompasses the management and integration of different kind of information. Besides, some of the aspects related with this concept should be analysed in the early stages of design. These challenges are forcing the building professionals to interact among each other in order to find positive synergies among different subjects. Therefore it is necessary to create a process that connects these different subjects (Mora et al., 2011).

The Integrated Design Process is the process that intends to fulfil this need. It helps the client and the designer to select optimal cost solutions. The IDP consists in an integrated approach that provides more positive results and high-performance levels (Larsson, 2009). This process includes the active and continued participation of all building stakeholders (Mora et al., 2011). The basic principle of IDP is that the later a sustainable related measure is applied, the bigger the costs and the lower the intervention possibilities.

Another process that should be considered in order to obtain a proper building management is commissioning. Commissioning is a systematic and documented process that ensures that the operational needs of the owner are achieved, that the system operate efficiently and that the building workers and users receive education that ensures the proper operation of the building systems. The commissioning should occur across all building stages since the predesign till the operation phase.

The building systems are one of the main contributors to the building energy consumption. Therefore, an adequate management of these systems will carry significant economic savings. A building with commissioning has operational costs between 8% to 20% inferiors than a building without this process (GSA, 2005).

4.3 *Key Indicators Selected*

Due to their importance regarding sustainable buildings, nineteen indicators related with the three main sustainability dimensions (environment, society and economy) were chosen.
The indicators selected were presented in Table 4.

Table 4. Sustainability indicators selected.

DIMENSION	CATEGORIES	SELECTED INDICATORS
ENVIRONMENT	Energy and Emissions	Non-renewable primary energy
		Renewable primary energy
		Green House Gases emissions
	Water	Water consumption
	Materials and Waste	Materials embodied energy
		Ozone depletion potential
		Acidification potential
		Eutrophication potential
		Photochemical oxidation potential
		Reused and recycled materials
		Responsible sourcing materials
		Waste production
SOCIETY	Users health and comfort	Indoor air quality
		Lightning
		Thermal comfort
		Acoustic comfort
	Process quality	Integrated design project
		Commissioning
ECONOMY	Economy	Life Cycle Costs

5 CONCLUSIONS

Through the revision of the results obtained in some European initiates, developed with the goal of select sustainability key indicators, was possible to observe that despite all the efforts, there are still some different between the lists of key indicators developed. However it was also possible to observe that there are some indicators whose selection is consensual among different BSA tools.

However, when selecting a set of indicators to assess sustainability, it is important to analyse the most significant buildings impacts and the socio cultural context.

The work presented in the paper selects a set of indicators that will be used in the cost-benefit analysis to sustainable construction. Due to the goal of the work, some specificities were applied in the selection of indicators. Nineteen indicators were selected and distributed across the three sustainability dimensions, environment, society and economy.

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