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Article

Building Sustainability Assessment

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Abstract: Although social, economic, and cultural indicators are of substantial importance to the concept of sustainable building, this concept is usually related to environmental characteristics. Any building level assessment method is complex and involves contradictory aspects. Moreover, emphasizing qualitative criteria only increases confusion. R&D and standardization are thus concentrated to transparency and usability of the environmental methods. Other directions of research aim at performance-based design and methods to take regional and cultural aspects into account. In this paper, the perspectives of the sustainability assessment of a whole building are presented, based on a state of the art, feasibility study on performance analysis and the development of an extended life-cycle assessment for buildings. Using various tools, and based on the case studies of building sustainability assessment, environmental indicators were often shown to be of lesser importance than the other, soft ones. The first steps in the development of a building sustainability assessment method for Portuguese residential buildings will be presented and discussed in the end.

Keywords: sustainability; assessment; building

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1. Introduction

A building project can be regarded as sustainable only when all the various dimensions of sustainability (environmental, economic, social, and cultural) are dealt with. The various sustainability issues are interwoven, and the interaction of a building with its surroundings is also important. The environmental issues share, in common, concerns which involve the reduction of the use of non-renewable materials and water, and the reduction of emissions, wastes, and pollutants. The following goals can be found in several building sustainability assessment methods: optimization of site potential, preservation of regional and cultural identity, minimization of energy consumption, protection and conservation of water resources, use of environmentally friendly materials and products, a healthy and convenient indoor climate, and optimized operational and maintenance practices.

The purpose of sustainability assessments is to gather and report information for decision-making during different phases of the construction, design, and use of a building. The sustainability scores or profiles, based on indicators, result from a process in which the relevant phenomena are identified, analyzed, and valued. Two extreme trends can be recognized at the moment: on one hand, the complexity and diversity of indicators from different operators, and on the other hand, the evolution towards better usability through a common understanding and simplicity.

The development of assessment methods and respective tools are a challenge both for in academia and in practice. A major issue is that of managing the flows of information and knowledge between the various levels of indicator systems. A variety of sustainability assessment tools are available on the construction market, and they are widely used in environmental product declarations (e.g., BREEAM in the U.K. and LEED in the U.S.) [1]. There are also Life-cycle assessment (LCA)-based tools available that are especially developed to address the building as whole, e.g., Eco-Quantum (Netherlands), EcoEffect (Sweden), ENVEST (U.K.), BEES (U.S.), ATHENA (Canada) and LCA House (Finland). A comparison of the contextual and methodological aspects of tools has been made before by other authors [2]. The majority of the tools, even though they are designed to consider the whole building, including energy demand, *etc.*, are developed based on a bottom-up approach, *i.e.*, a combination of building materials and components sums up to a building [3]. Tools to support decision-making, in accordance with the principles of performance-based design, have also been developed (mainly in research communities).

The assessment tools, either environmental or performance-based, are under a constant evolution in order to overcome their various limitations. The main goal, at the moment, is to develop and implement a systematic methodology that supports the design process of a building. This methodology should contribute to the most appropriate balance between the different sustainability dimensions, while being at the same time practical, transparent, and flexible enough. The method should be easily adaptable to different building types and to constant technological development.

In this paper, approaches to incorporating the three sustainability dimensions within a building project are presented and discussed, based on a state of the art feasibility study. In a more thorough way, sustainability deals with the concepts of eco-efficiency and cost-efficiency, which result from a holistic building performance analysis. After this, the potential to introduce the economic and social impacts (“soft indicators”) in the original environmental LCA methodology is studied, and the new developments and perspectives for the Building Sustainability Assessment (BSA), using global indicators, are presented.

2. Approaches to Building Sustainability

2.1. Sustainability Indicators of a Building Project

The sustainability indicators of the construction and real estate sector give information about the influences of the industry as a whole, and about the impacts of the construction and operation of buildings and other built assets. Different approaches for indicators exist due to differences between societies, industrial traditions, environment, and geography.

The sustainability indicators for a building project can be selected from various lists prepared at the level of the government, sector, and community. Agenda 21 [4] states that the framework of relevant issue areas should be based on the assumption that a sustainable building approach includes all factors that may affect the natural environment or human health. For a contractor or facility manager, it is important to differentiate between the criteria and tools used to assess technology at the generic or global level, and the approach used at the site specific application or local level [5]. In spite of some differences between the lists of indicators, most of them deal directly or indirectly with the following key issues: resources consumption, environmental pressure, energy and water efficiency, indoor air quality, comfort, and life cycle costs.

An indicator is expressed by a value derived from a combination of different measurable parameters (variables). Indicators have to be defined in a clear, transparent, unambiguous, and correct way, even before addressing the concern of whether they relate to and evaluate several parameters. The indicators are usually grouped (aggregated, categorized), and further various aggregated indicators may create subgroups in a hierarchical system.

2.2. Managing and Assessing Building Sustainability

Building Sustainability Assessment (BSA) methods can be oriented to different scales of analysis: building material, building product, construction element, independent zone, building and the neighborhood. By analyzing the scopes of the most important sustainability support and assessment systems and tools, it is possible to distinguish three types of assessment methods:

- Systems to manage building performance (Performance Based Design);
- Life-cycle assessment (LCA) systems;
- Sustainable building rating and certification systems.

2.2.1. Managing Building Performance

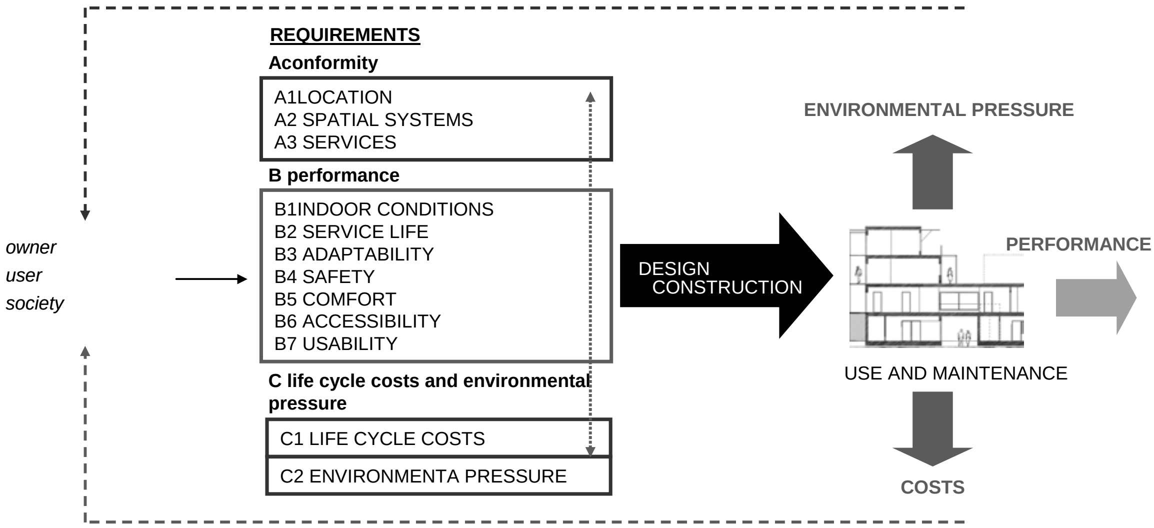
Performance Based Building is an approach to building-related processes, products, and services, with a focus on the required outcomes (the ‘end’). This approach allows for any design solution (the ‘means’) which can be shown to meet design objectives [6].

The comprehensive implementation of the performance approach is dependent on further advancement in the following three key areas: the description of appropriate building performance requirements, the methods for delivering the required performance, and the methods for verifying that the required performance has been achieved.

The main purposes of generic hierarchical model are to provide a common platform for defining the desired qualities of a building and to develop a common language for different disciplines, as well as to serve as a basis for the development of design and technical solutions. The choice of the objectives in the hierarchical presentation also shows, to some extent, the values of the developer.

Based on the hierarchy of performance objectives and their targeted qualities, alternate design and technical solutions can be developed. The capability of different solutions to fulfil the performance criteria can be studied with verification methods. Figure 1 represents a generic model of a building's performance analysis. Similar hierarchies are introduced by several organizations.

Figure 1. Example of a generic model for a building's performance analysis (VTT ProP®).



This kind of method provides some important benefits to both end users and other participants in the building process, since it promotes substantial improvements in the overall performance of the building, encourages the use of construction solutions that better fit the use of the building, and promotes a better understanding and communication of client and user requirements.

Tools to support decision-making, in accordance with the principles of performance based design, have been developed mainly in research communities. An example is the EcoProp® software (Finland).

2.2.2. Integrated Life-Cycle-Analysis of Buildings

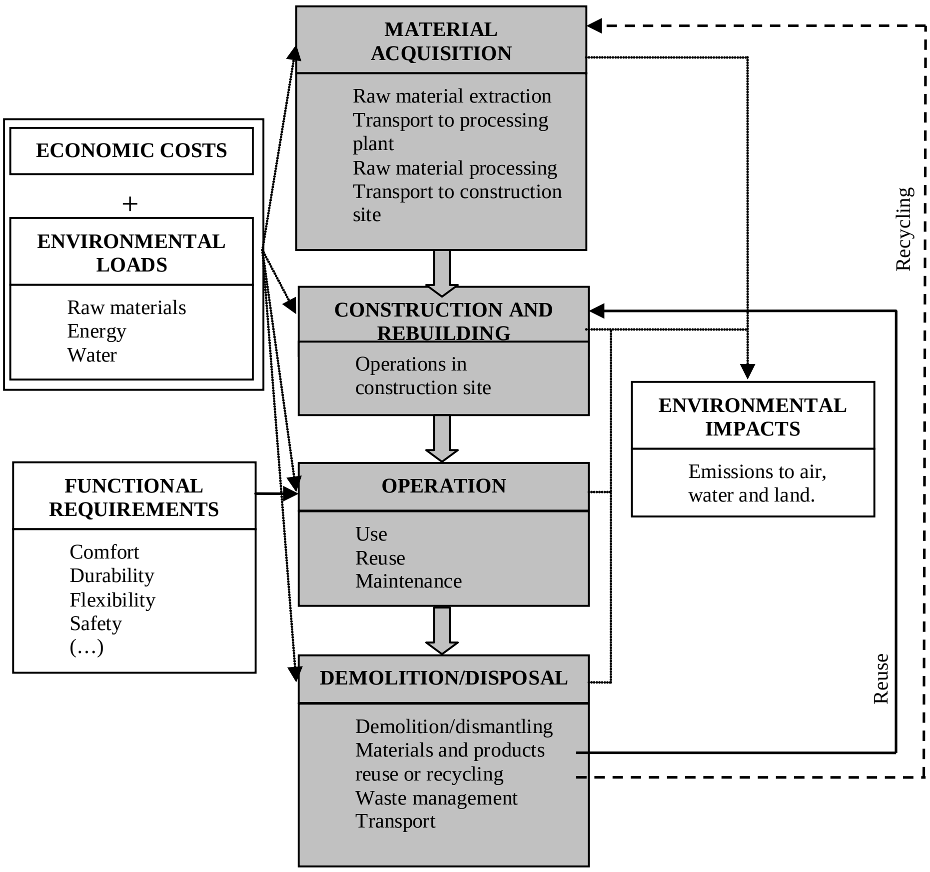
The complete Building Sustainability Assessment (BSA) comprises the ways in which built structures and facilities are procured and erected, used and operated, maintained and repaired, modernized and rehabilitated, and finally dismantled and demolished, or reused and recycled. Adoption of environmental LCA in buildings and works is a complex and tedious task. A building incorporates hundreds and thousands of individual products, and in a construction project, there might be tens of companies involved. Further, the expected life cycle of a building is exceptionally long (tens or hundreds of years).

The life-cycle of a building project starts before any physical construction activities and ends after its usable life. Figure 2 shows an integrated LCA of the building stages.

In the first BSA methods, the concept of sustainable construction was confused with the concept "low environmental impact construction". Therefore these methods failed to enter the mainstream sustainable development discourse. More recent BSA methods include the economic performance analysis in the evaluation. The economic assessment is an important factor in the success of any new approach in construction that includes sustainable principles. Demand for sustainable construction is influenced by buyer perception of the first costs *versus* the life cycle costs of sustainable alternatives [7].

At the environmental performance level, life-cycle inventory analysis (LCI) can be extremely complex and may involve a dozen individual unit processes in a supply chain (e.g., the extraction of raw resources, various primary and secondary production processes, transportation, among others) as well hundreds of tracked substances. The more rigorous the LCA methods are, the more data intensive they are. Therefore, the assessment process can involve significant costs of collecting data and keeping it updated, particularly in a period of considerable changes in materials manufacturing processes. Some data needed for the LCA is expensive and difficult to obtain, and is most often kept confidential by those manufactures that do undertake the studies. According to some authors [8], the databases do not include all the needed information for many of the relevant building products and components, nor for the construction process itself. Therefore, the researchers concluded that it is essential for LCA tools to allow the editing of existing variables and the addition of new ones according to local conditions and constant technological development.

Figure 2. The integrated LCA of the building stages.



The goal of some BSA methods is to simplify the LCA for practical use. The simplified LCA methods that currently exist are not comprehensive or consistently LCA-based, but they play an important role in promoting sustainable buildings. More accurate BSA tools integrate environmental assessment, life cycle costs, and the methods needed to verify if the required performance has been achieved. LCA-based methods are used to compare solutions to help decide which solution corresponds to the best compromise among the different sustainability dimensions.

2.3. Sustainable Building Rating and Certification

The rating and certification systems and tools are intended to foster more sustainable building design, construction, operation, maintenance, and disassembly or deconstruction by promoting and making possible a better integration of environmental, societal, functional, and cost concerns with other traditional decision criteria.

These systems and tools can both be used to support the sustainable design, since they transform the sustainable goal into specific performance objectives to evaluate the overall performance. There are different perspectives in different sustainable building rating and certification approaches, but they have certain points in common. In general, these systems and tools deal, in one way or another, with the same categories of building design and life cycle performance: site, water, energy, materials, and indoor environment.

Nearly all building sustainability rating and certification methods are based in local regulations or standards, and in local conventional building solutions. The weight of each parameter and indicator in the evaluation is predefined according to local socio-cultural, environmental, and economic contexts, and therefore most of the approaches developed so far can only have reflexes at local or regional scales. However, there are a few examples of global scale methods. These kind of methods are, above all, used at the academic level, since the requisite reference cases have to be constructed and separately assessed for each building type, which is a time consuming and expensive process.

There are three major building rating and certification systems that provide the basis for the other approaches used throughout the world: the Building Research Establishment Environmental Assessment Method (BREEAM), which was developed in the U.K., the Sustainable Building Challenge Framework (SBTool), which was developed by the collaborative work of 20 countries, and the Leadership in Energy and Environmental design (LEED), which was developed in the U.S.A.

3. Development of Building Sustainability Assessment

3.1. Scope of the Work

The Portuguese building technologies and the indoor environmental quality standards are quite different from most European countries. The first situation is mainly related to economic and socio-cultural constraints, while the second is related to the mild climate. This reality normally hinders the use of foreign decision support and sustainability assessment methodologies without prior adaptation of the list of parameters, weights, and almost all benchmarks. Another important reason for the delay in the real implementation of the sustainable assessment is the huge amount of parameters that project teams have to deal with: many of the methodologies presented in the sections above embrace hundreds of parameters. Most of these parameters are not standard in Portugal and are difficult to deal with for many project teams.

This study intends to be the basis for the future development of an advanced residential building sustainability rating tool, and is to be especially suitable for Portuguese traditions, climate, society, and national standards. The research aims to cope with the mentioned problems and toward the real implementation of building sustainability assessment in Portugal. The name of the methodology that is under development is the Methodology for the Relative Sustainability Assessment of Residential Buildings (MARS-H, from the Portuguese acronym).

In this section, steps to establish the methodology are presented. The indicators inside each sustainable dimension, and their related parameters, will be presented. Additionally, the calculation of the weights will be discussed. This calculation will be based in the local environmental, socio-economic, and legal contexts, and in the type of building that is going to be assessed.

First of all, system boundaries are presented. Then, the approach can be divided into four major stages: selection of indicators and parameters, quantification of parameters, normalization and aggregation of parameters, and representation and the global assessment of a project.

3.2. System Boundaries

In the first stage, the methodology is being developed to assess residential buildings. Most of the Portuguese construction market is related to the residential sector, and therefore, the development of a methodology to support and to rate sustainable residential buildings is a priority.

The object of assessment is the building, including its foundations and external works, within the area of the building site. The impacts of the building upon the surroundings and urban environment are not considered. Some authors concluded that restricted scales of study (corresponding for a single building for example) are too limited to take into account sustainable development objectives correctly [9]. Nevertheless, sustainable urban planning is normally limited to municipalities and regional authorities and therefore, it is more rational and straightforward to limit the physical system boundary to the building itself (or part of it) together with the site. This way, the methodology excludes construction works outside the construction site (including networks for communication, energy, and transportation).

The life cycle's period boundary should represent the whole life-cycle stages of the building. In a new building, it will consider all life-cycle stages, from construction to final disposal, and in existing buildings, the temporal boundary will start from the moment of the intervention to the final disposal. Besides the time boundary, two other important aspects to define are the hours of normal occupation, the usage of the building, and the building's occupational density.

3.3. Selection of Indicators and Parameters

After defining the time and physical boundaries of the methodology, the next step is to choose the indicators and related parameters (within the three sustainable development dimensions) that are going to be used to assess the objectives of a project. A parameter is a sign, or a signal, that relays a complex message, from potentially numerous sources, in a simple and useful manner [10]. Therefore, the main three objectives of the parameters are: simplification, quantification, and communication [11].

Categories and related parameters are the basis of the methodology, since objectives and results will be conditioned by them.

Figure 3 illustrates the parameters that are considered in the methodology under development. Other parameters could be included in further phases of development.

Figure 3. Indicators and related parameters considered in the MARS-H tool.

Assessment Objectives

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Indicators and Parameters to Assess

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Environmental Performance	**Societal Performance**	**Economic Performance**
• **Climate change:** Global warming potential. • **Emissions to the air, water and soil:** Destruction of the stratospheric ozone layer; Acidification potential; Eutrophication potential; Formation of ground-level ozone; Inert waste to disposal; Hazardous waste to disposal. • **Water efficiency:** Potable water use; Rain water use. • **Resources depletion:** Land use; Materials resource depletion; Fossil fuel depletion potential.	• **Hydrothermal comfort:** Relative humidity; Winter thermal performance; Summer thermal performance; • **Indoor air quality:** Air suspension of solid particles; Carbon monoxide; Carbon dioxide; Ozone; Formaldehyde; Organic volatile compounds. • **Acoustic comfort:** Airborne sound insulation; Impact sound insulation; Reverberation time. • **Visual comfort:** Natural lighting use; Illumination.	• **Life-cycle costs:** Costs before use of the building; Maintenance costs; Operational costs; Costs after building use; Residual value.

↓ ↓ ↓

Integrated Building Performance Analysis

↓

Representation and Global Index

In the evaluation of environmental performance, it is necessary to analyze the potential effects related to not only the building materials or products, but also to the operation of the building. For example, the assessment of fossil fuel depletion for a building life cycle is based on its materials or products' embodied energy (energy consumed in extraction, transport, manufacture, and installation), plus the operational energy needed to run the building over its lifetime.

The definition of the environmental indicators and parameters is based on the work that is being carried out in the European Centre for Normalization [12]. The methodology uses the same indicators and parameters that the experts found relevant in the building environmental performance assessment.

At the societal performance assessment, the methodology considers the parameters related to the health and comfort performance of buildings during their use and operation. In order to facilitate its use and understanding by all the Portuguese construction market's actors, the methodology does not consider parameters that can raise some kind of complexity and subjectivity in the assessment. The list of societal parameters presented in Figure 1 reflects the functional requirements of a residential building, according to national construction codes.

The economic performance parameters were defined in order to include all costs related to a building's life-cycle, from cradle to grave. The economical performance analysis is not complete unless the residual value is evaluated. The residual value of a system (or component) is the market value of it at the end of its service life, or at the end of the study period.

3.4. Quantification of Parameters

After selecting the parameters, it is necessary to proceed with their quantification. Quantification is essential for comparing different solutions, aggregating parameters, and accurate assessing solutions. The quantification method should be anticipated. There are several quantification methods: previous studies results, simulation tools, expert opinion, databases processing, *etc*. [13].

At the level of the quantification of the environmental parameters, there are some aspects to overcome. These aspects mainly deal with the availability of fundamental local LCI environmental data for all construction materials and products used in buildings. While there is no local LCI data, it is possible to use the information given in Environmental Products Declarations (EPDs) and other LCI databases from nearby countries. Another way is to use an external life-cycle assessment (LCA) tool to quantify the environmental parameters.

After quantifying the economic parameters listed in Figure 3, the next step is to calculate the sum of the total net present value (NPV) of the different costs. This sum will result in just one economic performance parameter: life-cycle costs.

3.5. Normalization of Parameters and Aggregation

The objective of the normalization of parameters is to avoid the scale effects in the aggregation of parameters inside each indicator and to solve the problem that for some parameters, "higher is better" while for others, "lower is better". Normalization is done using the Diaz-Balteiro [14], Equation 1.

$$\overline{P_i} = \frac{P_i - P_{*i}}{P_i^* - P_{*i}} \forall_i \qquad (1)$$

In this equation, P_i is the value of i^{th} parameter. P^*_i and P_{*i} are the best and standard values of the i^{th} sustainable parameter, respectively. The best value of a parameter represents the best practice available and the worst value represents the standard practice or the minimum legal requirement.

Normalization, in addition to turning dimensionless the value of the parameters considered in the assessment, converts the values into a scale bounded between 0 (worst value) and 1 (best value). This equation is valid for both situations: "higher is better" and "lower is better".

As stated before, building sustainability assessment across different fields involves the use of numerous indicators and tens of parameters. A long list of parameters with their associated values will not be useful for assessing a solution. The best way is to combine parameters with each other inside each dimension in order to obtain the performance of the solution in each indicator [15].

The methodology uses a complete aggregation method for each indicator, according to Equation 2.

$$I_j = \sum_{i=1}^{n} w_i . \overline{P_i} \qquad (2)$$

The indicator I_j is the result of the weighting average of all the normalized parameters $\overline{P_i}$; w_i is the weight of the i^{th} parameter. The sum of all weights must be equal to 1.

Difficulties in this method lie in the setting of the weight of each parameter and in the possible compensation between parameters. Since weights are strongly linked to the objectives of the project and to the relative importance of each parameter in the assessment of each indicator, higher weights must be adopted for parameters of major importance in the project. The possible compensation between parameters is limited inside each indicator.

Table 1. Relative importance weighting of the environmental parameters (adapted from the Science Advisory Board study [16,17]).

Indicator	Impact parameter	Parameter's Weight (%)	Indicator's Weight (%)
Climate change	Global warming potential	22	22
Emissions	Destruction of the stratospheric ozone layer	15	47
	Acidification potential	15	
	Eutrophication potential	15	
	Formation of ground-level ozone (smog)	17	
	Inert waste to disposal [1]	6	
	Hazardous waste to disposal [2]	32	
Water efficiency	Potable water use [3]	75	4
	Rain water use [3]	25	
Resources depletion	Land use [1]	37	27
	Materials resource depletion [1]	37	
	Fossil fuel depletion potential	26	

[1] This parameter was connected with the habitat alteration impact category of the SAB study.
[2] This parameter was connected with the habitat alteration and ecological toxicity impact categories of the SAB study.
[3] This parameter was connected with the water intake impact category of the SAB study.

There are no national impacts scores concerning the weight for each environmental parameter, in terms of its relative importance to overall performance. Nevertheless, there are some internationally accepted studies that allow an almost clear definition. Two of the most consensual lists of values are based on a US Environmental Protection Agency's Science Advisory Board (SAB) study [16,17] and a Harvard University study [18]. Whenever there is not local or regional available data, it is suggested that SAB's weights be used in MARS-H. Table 1 presents the relative importance of the environmental parameters and indicators that are considered in the methodology. Values are adapted from the SAB's study.

Despite the fact that it is easy to quantify functional parameters, the manner in which each parameter influences the functional performance, and therefore the sustainability, is not consensual. This assessment involves subjective ratings and depends, above all, on the type of solution and on the evaluator's social-cultural and economic status. In this way, in a first approach, the methodology considers the same weight for all functional parameters. The MARS-H is being developed in order to accommodate a more consensual distribution of weights.

3.6. Representation and Global Assessment of a Project

One important feature of the methodology is the use of graphical representations to monitor the different solutions that are analyzed. The representation is global, involving all the considered objectives (indicators).

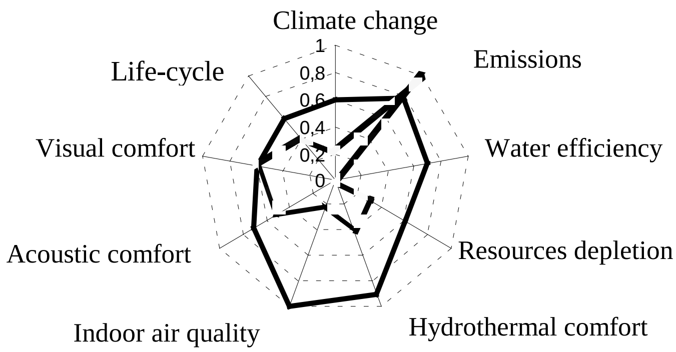
The tool that is used to graphically integrate and monitor the different parameters is the "radar" or Amoeba diagram. This diagram has the same number of rays as the number of parameters under analysis and is called the sustainable profile. In each sustainable profile, the global performance of a solution is monitored and compared with the performance of the reference solution. The closer to the center a solution is, the better this solution is. It is also possible to verify the solution that best compromises the different parameters used in the assessment. Figure 4 represents two sustainable profiles that result from the application of the MARS-H to two hypothetical solutions.

The assessment of a project will come from the visualization of all indicators. By analyzing Figure 4, it is possible to verify that the solution that best compromises the objectives of the project is the most circular one. MARS-H is an iterative design method, which is used to identify and to overcome the weaknesses of a project. But it cannot be used to assess the sustainability of a solution in an absolute way. It is used to compare different solutions in order to recognize the one that best suits the objectives of the project. After assessing the performance of a solution within all indicators, as presented in Figure 2, the next step is to combine the indicators with each other inside each dimension in order to obtain the environmental, societal, and economic performance of each solution. The methodology used for integration is presented in Equation 3, for the environmental dimension.

$$P_{Env} = \sum_{i=1}^{n} I_{Env_i} . w_{Env\,i} \tag{3}$$

P_{Env} represents the environmental performance of the solution, I_{Envi}, the ith environmental indicator, and w_{Envi} is the weight of the ith indicator.

Figure 4. Two sustainable profile graphical representations that result from the application of the MARS-H to two hypothetical solutions.



The last step is the quantification of the Sustainable Score (SS). SS is a single index that resumes the global performance of a solution. The closer to 1 a solution's sustainable score is, the more sustainable the solution is. The aggregation method used to calculate the sustainable score is presented in Equation 4.

$$SS = P_{Env}.w_{Env} + P_{Soc}.w_{Soc} + P_{Eco}.w_{Eco} \tag{4}$$

Because the main aim of sustainable development is to find a balanced development within the three dimensions, MARS-H considers, as standard, an equal weight for each dimension in the integrated assessment. However, users can use another set of weights, according to specific local priorities. In order to prevent difficulties in sustainability assessment, this unique score should not be used alone to rate sustainability, because there is the possible compensation between indicators, and moreover, the solution has to be the best compromise between all different indicators.

4. Conclusions

The sustainable design, construction, and use of buildings are based on the evaluation of the environmental pressure (related to the environmental impacts), social aspects (related to the users comfort and other social benefits), and the economic aspects (related to the life-cycle costs).

This paper presented some approaches to the building sustainability assessment (BSA) and the principles of one tool that is being developed to assist the Portuguese design teams in sustainable design. Despite the numerous studies about this, there is a lack of a worldwide accepted method for assisting architects and engineers in the design, production, and refurbishing stages of a sustainable building. The actual LCA methods and building rating tools have a positive contribution in the fulfilment of sustainable developing aims, but they have their subjective aspects. For example, the weight of each parameter and indicator in the evaluation may vary between methods. For this reason, the use of Performance Based Building methods (supported in the best construction codes and practices) continues to be the most objective approach for guiding the design teams to archive the performance objectives.

The sustainable building rating tool that is being developed is intended to contribute positively to sustainable construction in Portugal through the definition of a list of goals and aims, that are easily understandable by all involved in the construction market, and which are compatible with the Portuguese construction technology background. Nevertheless, there are still two important steps to fulfill before applying the methodology: the validation of the list of indicators and parameters and the assessment of the societal weights. Although the list of indicators and parameters is partially based on a framework for assessment of integrated building performance (CEN/TC 350), further work includes the method's validation in Portugal through thematic interviews and surveys to experts in each dimension of sustainable development. The weight of each health and comfort related parameter is now being assessed through experimental works and subjective evaluations.

The uptake of sustainable building design is in its infancy. Even with the actual limitations linked to the different methods available, the widespread use of assessment methods is gradually gaining more traction in the construction sector. Globally, the urgency to turn economic growth toward sustainable development will require more efforts in the construction sector too.

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