

Assessment of Building Sustainability

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

1 INTRODUCTION

A building project can be regarded as sustainable only when all the various dimensions of sustainability –environmental, economic, social and cultural ones - are dealt with. The various sustainability issues are interwoven, and the interaction of a building and its surroundings is also important. The environmental issues are in common those which cope with reducing use of non-renewable materials and water, and reducing emissions, waste and pollutants. The following goals for an overall assessment can be found in several agendas: 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, healthy and convenient indoor climate and optimized operational and maintenance practices.

The purpose of sustainability assessments is to report information for decision-making during different phases of a new-building project or existing building. This is done in the form of quantified measures of various indicators that tell about the expected impacts during the life-cycle or phases of the life-cycle. The scores or profiles are derived from a process in which the relevant issues are identified, analyzed, categorized and valued. Development of a life-cycle method or tool or use of them should follow the standard series ISO 14040 – 14043.

A variety of sustainability assessment tools is available on the construction market, and they are widely used in environmental product declarations. Several comparative studies on contextual and methodological aspects of tools has also been made, like e.g. by Forsberg and Malmberg (2004).

The majority of the tools is developed based on a bottom up approach, i.e. a combination of building materials and components sums up to a building, and this even though they are designed to consider the whole building including energy demand, etc (Erlandsson & Borg 2003). Allacker and De Troyer (2006) comment that it is not correct to equate a building to a sum of its constituent components due to the influence of the (architectural) design on overall impacts.

Kohler et al (1997) emphasize that only the building level provides a coherent functional unit that leads to the need of modular data. This is because

- buildings have the longest life time of industrially produced goods
- current costs and energy use are in general much larger than the initial investment
- there are complex relations between initial and current costs
- one-of-a-kind character of buildings makes comparisons difficult
- design process is not linear and has many feedback, the same data are used several times with different accuracy

Tools to support decision-making in accordance with 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 design process of a building. The methodology should result to the most appropriate balance between the different sustainability dimensions, and be practical, transparent and flexible at the same time. It should be easily adaptable to the different kinds of buildings and to the constant technology evolution.

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

2 GENERIC METHODS OF BUILDING SUSTAINABILITY

2.1 *General requirements of methods*

According to CIB (1999), the relevant issue areas of a sustainable building should include 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 (Environmentally Sound Technologies 2003).

Hermann et al (1997) have prepared a list of requirements for generic tools of building sustainability assessment that have been agreed with by many researchers:

- adaptable to building life cycle phases, different actors and different decision levels
- adaptable to different types of impacts and effects
- suit to the usual professional working environment
- scaleable – allowing a zoom.

According to Herman et al (1997), "the evaluation of the design and of the effective performance of a building is always a very complex issue. There is no simple and transparent performance optimum. Multi-criteria methods are of not much help in the real design process. The best evaluation model is probably constraint satisfaction. The target performances of buildings are considered as constraints forming an n-dimensional performance space. The design alternatives must be inside this space and the optimisation depends on aesthetic, cultural, social, psychological qualities."

2.2 *Managing and assessing building sustainability*

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

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

i) 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 would allow for any design solution (the 'means') which can be shown to meet design objectives (Koukkari, 2005).

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; methods for delivering the required performance; methods for verifying that the required performance has been achieved.

The main purpose for a generic hierarchical model is to provide a common platform to define the desired qualities of a building and to develop a common language for different disciplines as well as to serve as a basis for development of design and technical solutions. The choice of the objectives in the hierarchical presentation shows also 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 building's performance analysis.

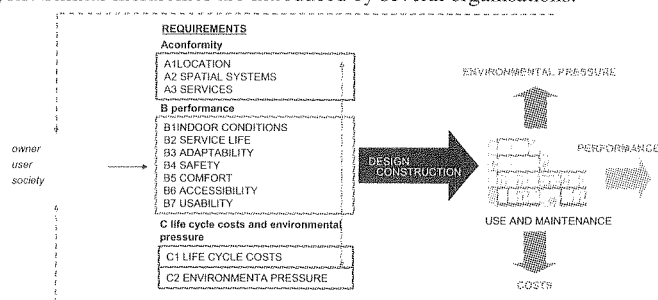


Figure 1. Example of a generic model of building's performance analysis (VTT ProP®).

This kind of method is providing some important benefits to both end users and to the 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 users requirements.

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

ii) Integrated Life-Cycle-Analysis of buildings

The complete building sustainability assessment (BSA) comprise the ways in which built structures and facilities are procured and erected, used and operated, maintained and repaired, modernised and rehabilitated, and finally dismantled and demolished or reused and recycled. 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 LCA methods the concept of sustainable construction was confused with the concept "low environmental impact construction", therefore they failed to enter the mainstream sustainable development discourse. More recent LCA methods include the economic performance analysis in the evaluation. Demand for sustainable construction is influenced by buyer perception of the first costs versus life cycle costs of sustainable alternatives (Kibert, 2003).

The more rigorous the LCA methods are the more data intensive they are, and therefore the assessment process can involve enormous expenses 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 Pushkar, Becker and Katz (2005), the databases do not include all the needed information for many of the relevant building products and components, nor the construction process itself. Therefore they conclude that

LCA tools that editing of existing variables and adding new ones according to local conditions, is essential.

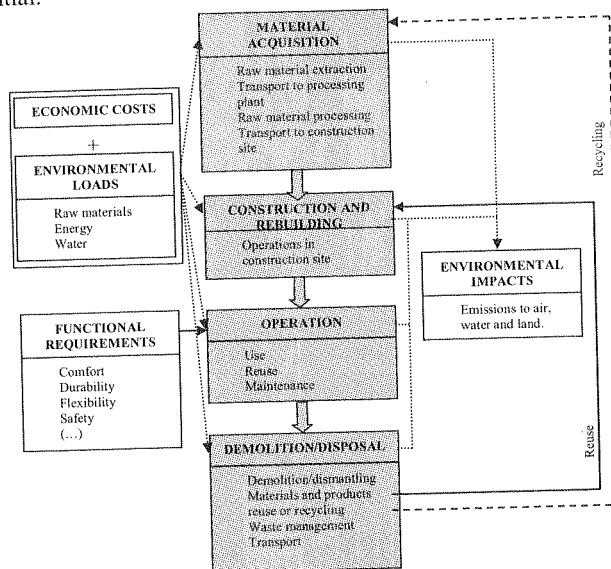


Figure 2. Integrated LCA of the building stages.

The goal of some BSA methods is to simplify the LCA for practical use. The simplified LCA methods that currently exist aren't comprehensive or consistently LCA-based but they play an important role in turning the buildings more sustainable. More accurate BSA tools will integrate environmental assessment, life cycle costs and 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/deconstruction by promoting and making possible a better integration of environment, societal, functional and cost concerns with other traditional decision criteria.

These systems and tools can be used both to support the sustainable design, since they transform the sustainable goal into specific performance objectives and to evaluate the overall performance. There are different perspectives in different sustainable building rating and certification, 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.

Near all of the sustainable building 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 reality. Therefore the major part of them can only have reflexes at local or regional scales. However, there are some few examples of global scale methods. This 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: Building Research Establishment Environmental Assessment Method (BREEAM), developed in U.K.; Sustainable Building Challenge Frame-

work (SBTool), developed by the collaborative work of 20 countries; Leadership in Energy and Environmental design (LEED), developed in U.S.A..

3 DEVELOPMENT OF BUILDING SUSTAINABILITY ASSESSEMENT

3.1 *Scope of the work*

The Portuguese building technologies and the indoor environment quality standards are quite different from most European countries. The first situation is mainly related to the fact that Portugal was not involved in the II World 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 that is clogging 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 them not standard in Portugal and 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, especially to be suitable in Portuguese traditions, climate, society and national standards. The research aims to cope with the mentioned problems and to real implement building sustainability assessment in Portugal. The name of the methodology that is under development is Methodology for the Relative Sustainability Assessment of Residential Buildings (MARS-ER from the Portuguese acronym).

In this section, steps to establish the methodology are presented. The indicators inside each sustainable dimension and their associated parameters will be presented. Additional it will be discussed how to calculate the weights, based in the local environmental, socio-economic and legal reality and in the type of building that is going to be evaluated.

First of all, system boundaries are presented. Then, the approach can be divided in 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*

At a first stage, the methodology is being developed to assess residential buildings. Most of the Portuguese construction market is related with the residential sector and therefore the development of a methodology to support and rate this sector's sustainability 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 in the surroundings and in urban environment won't be assessed. 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 (Bussemey-Buhe, 1997). Although, sustainable urban planning is normally limited to municipalities and regional authorities, 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 of the site location and construction of the different networks for communication, energy and transportation outside of the site location.

The temporal methodology's 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 and use and the occupation density.

3.3 *Selection of indicators and parameters*

After defining the methodology's time and physical boundaries 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. According to Kurtz *et al* (2001) a parameter is a sign or a signal that relay a complex message, from potentially numerous sources, in a

simple and useful manner. Therefore the main three objectives of the parameters are: simplification, quantification and communication (Geissler, 2001).

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

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

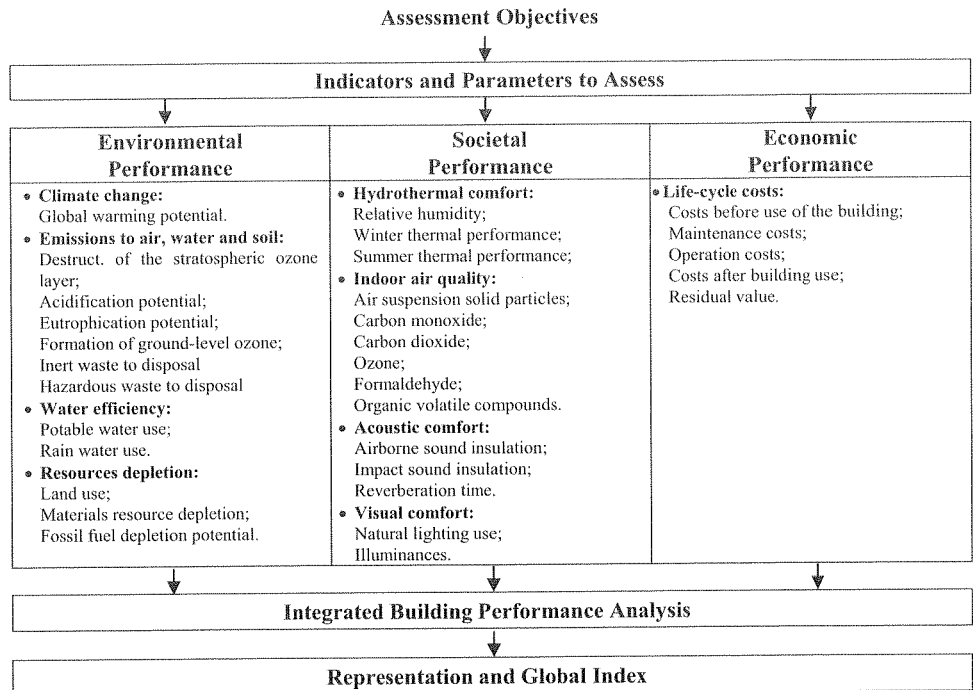


Figure 3. Indicators and related parameters considered in the MARS-ER tool.

In the evaluation of the environmental performance it is necessary to analyse the potential effects related not only with the building materials or products but also with the operation of the building. For example, the assessment of fossil fuel depletion for a building's life cycle is based in its materials or products embodied energy (energy invested 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 in the work that is being carried out in CEN/TC 350 WG1. The methodology uses the same indicators and parameters that the experts found relevant in the building environmental performance assessment.

In societal performance assessment, the methodology only considers the parameters related to the health and comfort performance of buildings during their use and operation. The methodology doesn't considers parameters that could raise some kind of complexity and subjectivity in the assessment, in order to facilitate its use and understanding by all Portuguese construction market's actors. 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 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 its remaining value at the end of the study period, or at the time it is replaced during the study period.

3.4 Quantification of parameters

After selecting the parameters it is necessary to proceed with their quantification. Quantification it is essential to compare different solutions, aggregate parameters and to accurately assess the solution. The quantification method should be anticipated. There are several quantification methods: previous studies results, simulation tools, expert's opinions, databases processing, etc. (Cherqui, 2004).

At the level of the quantification of the environmental parameters, there are some aspects to overcome, mainly in which regards to the availability of fundamental local LCI environmental data for all construction materials and products used in buildings. While there isn't local LCI it is possible to use the information given in Environmental Products Declarations (EPD's), and other LCI databases from nearby countries. MARS-RE recommends the use of the Central Europe's LCI data collected by Berge (Berge 2000). 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. Therefore in the assessment there will be just one economic 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 some parameters are of the type "higher is better" and others "lower is better". Normalization is done using the Diaz-Balteiro *et al.* (2004) Equation 1.

$$\bar{P}_i = \frac{P_i - P_{*i}}{P_i^* - P_{*i}} \forall_i \quad (1)$$

In this equation, P_i is the value of i^{th} parameter. P_i^* and P_{*i} are the best and standard value of the i^{th} sustainable parameter. 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 and involves the use of numerous indicators and tens of parameters. A long list of parameters with its associated values won't be useful to assess 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 (Allard, 2004).

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

$$I_j = \sum_{i=1}^n w_i \bar{P}_i \quad (2)$$

The indicator I_j is the result of the weighting average of all the normalized parameters \bar{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 setting 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.

In what concerns to the weights of the environmental parameters, there aren't national impacts scores for each environmental parameter, according to its relative importance to overall performance. Although, there are some international accepted studies that allow an almost clear definition. Two of the most consensual lists of values are based on a US Environmental Protec-

tion Agency's Science Advisory Board study (EPA, 2000).and a Harvard University study (Norberg-Bohm, 1992). Whenever there isn't a local or regional available data, it is suggested to use SAB's weights in MARS-RE. Table 1 presents the relative importance of environmental parameters and indicators that is considered in the methodology. Values are adapted from the SAB's study.

Table 1. Relative importance weights for environmental parameters, adapted from the Science Advisory Board study.

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.

In spite of being easy to quantify the functional parameters, the way as each parameter influences the functional performance and therefore the sustainability isn't consensual. This assessment involves subjective rating and depends, above all, on the type of solution and on the evaluator's social-cultural and economic status. This way in a first approach the methodology considers the same weight for all functional parameters. The MARS-RE 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 graphical representation for the monitoring of 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. Furthest to the centre is the solution, better it 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-RE to two hypothetical solutions.

The assessment of a project will come from the visualization of all indicators. Analysing figure 4 it is possible to verify that the solution that best compromises the objectives of the project is the most circular one. MARS-RE is an iterative design method, which is used to identify and to overcome the weaknesses of a project but it could not 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, as presented in Equation 8 for the environmental dimension.

$$P_{Env} = \sum_{i=1}^n I_{Env_i} \cdot W_{Env_i} \quad (8)$$

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

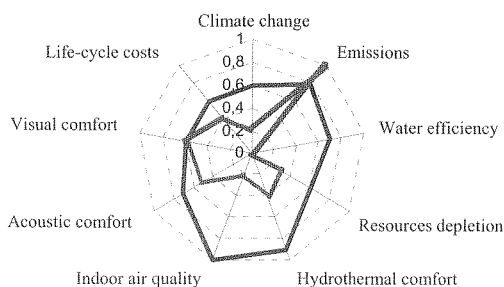


Figure 4. Sustainable profile.

The last step is the quantification of the Sustainable score (SS). SS is a single index that resumes the global performance of a solution. As nearest to 1 is the sustainable score, more sustainable is the solution. The aggregation method used to calculate the sustainable score is presented in Equation 6.

$$SS = P_{Env} \cdot w_{Env} + P_{Soc} \cdot w_{Soc} + P_{Eco} \cdot w_{Eco} \quad (3)$$

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

4 CONCLUSIONS

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 economic aspects (related to the life-cycle costs).

In this paper it was presented some approaches to the buildings sustainability assessment (BSA) and one tool that is being developed to assist the design teams in the sustainable design. Despite the numerous studies about it there is a lack of a worldwide accepted method to assist the architects and engineers in the design, production and refurbishing stages of a 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. For this reason, nowadays, the use of Performance Based Buildings methods, supported in the best construction codes and practices, to guide the design teams in order to archive the performance objectives, continues to be more objective than the use of rating tools.

The sustainable building rating tool that is being developed intends to contribute positively to the sustainable construction through the definition of a list of goals and aims, easily understandable by all intervenient in construction market, compatible with the European construction technology background. Although, there are still two important steps to fulfil before applying the methodology: validation of the list of indicators and parameters and assessment of the societal weights. Although the list of indicators and parameters is partially based in the framework for assessment of integrated building performance (CEN/TC 350), further work includes its validation in European countries through thematic interviews and surveys to experts in each dimension of the 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 of assessment methods is gradually

gaining more market in the construction sector. Globally, the urgency to turn the economic growth toward sustainable development will require more efforts in the construction sector, too.

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