# Sustainability Assessment of an Affordable Residential Building Using the SBTool$^{PT}$ Approach

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ABSTRACT: This paper will present the sustainability assessment of an affordable residential building block using the SBTool$^{PT}$ – H approach. This building block resulted from a cooperative housing project that fulfils some of the priorities of high-performance and low environmental impact buildings and is internationally recognised as a good example of a sustainable project. The aim of this study is to verify the usefulness of the SBTool$^{PT}$ approach in promoting sustainable buildings that have lower life-cycle costs when compared to conventional ones.

## 1 INTRODUCTION

### 1.1 *The developments in the sustainability building approach*

Due to the increasing awareness about the consequence of the contemporary model of development in the climate change and to the growing international movement toward high-performance/sustainable buildings, more and more the current paradigm of building is changing. This is changing both the nature of the built environment as well the actual way of designing and constructing a facility. This new approach is different from the actual practice by the selection of project teams members based on their eco-efficient and sustainable building expertise; increased collaboration among the project team members and other stakeholders; more focus on global building performance that on building systems; the heavy emphasis placed on environmental protection during the whole life-cycle of a building; careful consideration of worker health and occupant health and comfort through all phases; scrutiny of all decision for their resource and life-cycle implications; the added requirement of building commissioning; and the emphasis placed on reducing construction and demolition waste (Kibert, 2005).

Although there are several definitions for a sustainable building, generally speaking, it uses resources like energy, water, land, materials in a much more efficient way than conventional buildings. These buildings are also designed and used in order to produce healthier and more productive living, work and living environments, from the use of natural light and improved indoor environmental quality (Syphers et al, 2003). Therefore, sustainable building aims the proper balance between the three dimensions of the sustainable development: Environment, Society and Economy.

### 1.2 *The importance of the sustainable residential building affordable to all*

In Portugal, most of the impacts of the built environment in the sustainable development are related to the residential sector (Mateus, 2009). At the environmental level this sector is directly and indirectly related to the consumption of a great amount of natural resources (energy, water, mineral, wood, etc.) and to the production of a significant quantity of residues. For example, although Portugal has a mild climate, residential sector accounts for about 17% of the total national energy consumption (DGGE, 2005). Additionally, it uses a considerable amount of water resources, about 132 l/inhabitant/day of potable water, being a significant part of this capitation used in toilets (INAG, 2005). At the socioeconomic level and compared to other sectors, buildings is the most important sector, not only because about 10% of the global economy is related with its construction and operation, but also because it significantly influences the quality of life and heath of its inhabitants: in the developed countries, people are inside buildings in about 80% to 90% of the period of their life (Roodman and Lessen, 1995). Nevertheless, some studies in Portugal showed that most buildings are not sustainable in terms of operating and maintenance costs and do not provide a comfortable and healthy indoor environment for their occupants (Mateus, 2009). For example, the reality shows that 23% of the Portuguese residential buildings need to be repaired and their owners do not have the necessary income for the necessary investment (INE, 2001).

The abovementioned reality shows that the case for creating sustainable affordable housing is substantial. Compared to the conventional practice, the sustainable affordable houses concept is related to the creation of healthy homes with low operation costs, at a minimum level of environmental impacts. Another significant difference is that in affordable housing developers are motivated to consider durability and maintenance costs when selecting materials while for-profit developers only consider this issue if residents are willing to pay for upgrades from less expensive options (Syphers et al, 2003).

One of the most important barriers for the wider adoption of this concept is that many stakeholders do not recognize the benefits of the sustainable construction and the do not understand the potential higher capital cost implications. For instance, the adoption of solar collectors, photovoltaics, grey water recycling devices will lead necessarily to higher capital costs, but also to lower operation costs and therefore to costumer's satisfaction. Despite this, when planned and designed well, projects can achieve at least a basic level of sustainability with little to no additional cost (Kibert, 2005).

In the next sections, this paper will present an affordable residential building that was built in Portugal and its sustainability will be assessed using the building sustainability assessment tool SBTool$^{PT}$ – H.

## 2 PRESENTATION OF THE CASE STUDY

The case-study is a multifamily cooperative housing building block that is the Portuguese pilot - project of the European Program "SHE: Sustainable Housing in Europe" (http://www.she.coop).

The Portuguese pilot project was the second phase of the Ponte da Pedra housing state that was built in the municipality of Matosinhos, Northern Portugal (Figure 1). It is a multifamily social housing project, which promoter is NORBICETA - União de Cooperativas de Habitação, U.C.R.L. This project has two building blocks, a footprint of 3105m2, a total gross area of 14.852m$^2$ and 101 dwellings. It was co-sponsored by the project SHE and by the National Housing Institute (INH) and had the support of the FENACHE (national federation of social housing cooperatives), FEUP (Faculty of Engineering of the University of Porto) and UM (University of Minho). This project aimed to demonstrate the real feasibility of sustainable housing in Portugal and it succeed since it proved the practical feasibility of building a residential building with lower environmental impacts, higher comfort and lower life-cycle costs, when compared to a conventional one.

During the design phase, the project team adopted a series of priorities in order to create a sustainable affordable building block. The most important priorities were:

i) To use pre-developed land: this housing state was built in an area that was occupied by decayed industrial buildings (Figures 1 and 2). By contributing to the regeneration of the land and to the improvement of around urban area, this project had a positive local impact. On the other hand, due to the fact of not using new land it will contribute for the maintenance of local biodiversity;

ii) Energy efficiency: the primary energy consumption is about 25% of the local's conventional practice; it uses efficient lighting in public spaces; and solar collectors for hot water (Figure 3);

iii) Water efficiency: building is equipped with a rainwater harvesting system that guarantees at about 100% of the water supply for green areas and toilets (Figure 4); and it is equipped with low water flow devices (Figures 5 and 6).

iv) Improvement of the indoor air quality: all window frames are equipped with ventilation grids (Figure 7).

v) Management of household waste: all kitchens are equipped with containers for each of the four types of household solid waste (Figure 8); the outside containers are located nearby the building's entrance.

Figure 1. General exterior view of the building blocks.

Figure 2. Aspect of the local before the intervention.

Figure 3. Hot water solar collectors (thermodynamic system).

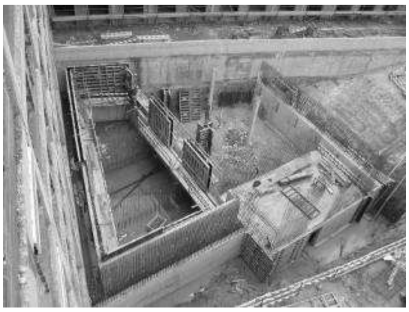

Figure 4. Rainwater tank (construction phase).

Figure 5. Low flow showers.

Figure 6. Double flush toilets (6/3 l).

Figure 7. Ventilation grids on window frames.

Figure 8. Containers for solid waste separation.

vi) Controlled costs: compared to the first phase of the Ponte da Pedra housing state (that have the same type of architecture but uses the conventional building technologies) the construction cost was about 9% higher. The promoter assumed part of this higher capital cost and the dwellings were sold at a price 5% higher than the first phase. According to the promoter, the turn-off of this higher capital cost will about 5 to 6 years. Nevertheless, dwellings were sold at an average price that was 20% bellow the local's average market practice.

## 3 USED BUILDING SUSTAINABILITY ASSESSMENT METHODOLOGY

Building sustainability assessment involves various relations between built, natural and social systems. Therefore it comprises hundreds of parameters, most of them interrelated and partly contradictory. To cope with this complexity and to support the sustainable building design, it is necessary to implement a real methodological work. The main objective of a systematic approach is to define sustainable building concept through tangible goals in order that, as a result of the sustainable design process, it is possible to achieve the most appropriate balance between the different sustainability dimensions (Mateus et al, 2008).

The study presented in this paper uses the SBTool$^{PT}$ methodology (Sustainable Building Tool adapted to Portugal). The SBTool is a building sustainability assessment method that result from the collaborative work of several countries, since 1996 and it was promoted by the International Initiative for a Sustainable Built Environment (iiSBE). This international involvement supported its distinction among the others methodologies, since SBTool was designed to allow users to reflect different priorities and to adapt it to the regional's environmental, socio-cultural, economy and technological contexts.

The Portuguese version of SBTool - SBTool$^{PT}$ - was developed by the Portuguese chapter of iiSBE, with the support of University of Minho and the company Ecochoice. In this methodology all the three dimensions of the sustainable development are considered and the final rate of a building depends on the comparison of its performance with two benchmarks: conventional practice and best practice. This methodology has a specific module for each type of building and in this paper the module to assess residential buildings (SBTool$^{PT}$ – H) was used.

The physical boundary of this methodology includes the building, its foundations and the external works in the building site. Issues as the urban impact in the surroundings, the construction of communication, energy and transport networks are excluded. Regarding the time boundary, it includes the whole life cycle, from cradle to grave.

Table 1 lists the categories (global indicators) and indicators that are used in the methodology to access residential buildings. It has a total of nine sustainability categories (summarizes the building performance at the level of some key-sustainability aspects) and 25 sustainability indicators within the three sustainability dimensions.

The methodology is supported by an evaluation guide and its framework includes (Figure 8):

i) Quantification of performance of the building at the level of each indicator presented in a evaluation guide;
ii) Normalization and aggregation of parameters;
iii) Sustainable score calculation and global assessment.

In order to facilitate the interpretation of the results of this study the main steps of the SBTool$^{PT}$ approach will be presented in the next sections.

### 3.1 *Quantification of parameters*

The evaluation guide presents the methodologies that should be used by the assessor in order to quantify the performance of the building at level of each sustainability indicator.

Table 1. List of categories and sustainability indicators of the SBTool$^{PT}$ methodology.

| Dimension | Categories | Sustainability indicators |
|---|---|---|
| Environ-ment | C1 – Climate change and outdoor air quality | P1 – Construction materials' embodied environmental impact |
| | C2 – Land use and biodi-versity | P2 - Urban density<br>P3 – Water permeability of the development<br>P4 - Use of pre-developed land<br>P5 – Use of local flora<br>P6 – Heat-island effect |
| | C3 – Energy efficiency | P7 – Primary energy<br>P8 – In-situ energy production from renewables |
| | C4 – Materials and waste management | P9 – Materials and products reused<br>P10 – Use of materials with recycled contend<br>P11 – Use of certified organic materials<br>P12 – Use of cement substitutes in concrete<br>P13 – Waste management during operation |
| | C5 – Water efficiency | P14 – Fresh water consumption<br>P15 – Reuse of grey and rainwater |
| Society | C6 – Occupant's health and comfort | P16 – Natural ventilation efficiency<br>P17 – Toxicity of finishing<br>P18 – Thermal comfort<br>P19 – Lighting comfort<br>P20 – Acoustic comfort |
| | C7 – Accessibilities | P21 – Accessibility to public transportations<br>P22 – Accessibility to urban amenities |
| | C8 – Awareness and edu-cation for sustainability | P23 – Education of occupants |
| Economy | C9 – Life-cycle costs | P24 – Capital cost<br>P25 – Operation cost |

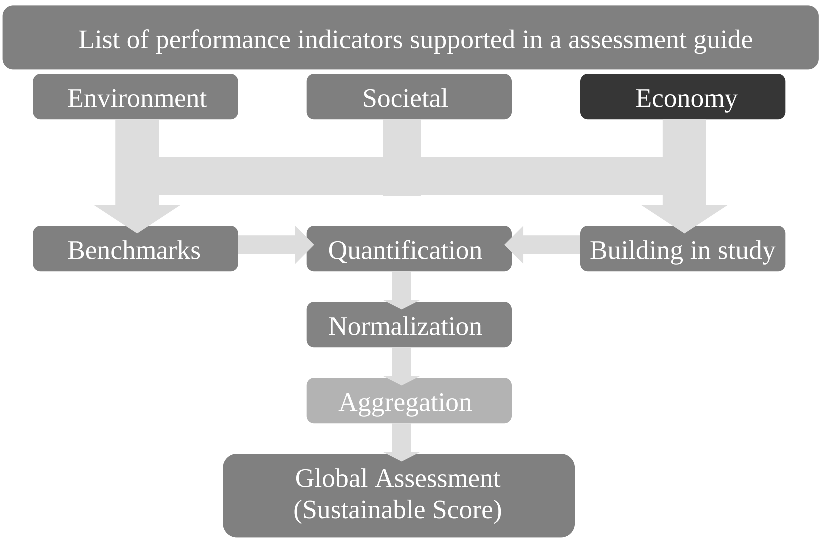


Figure 8. Framework of the SBTool$^{PT}$ methodology.

At the level of the environmental parameters, SBTool$^{PT}$ uses the same environmental categories that are declared in the Environmental Product Declarations. At the moment, there are limitations with this approach due to the small number of available EPD. Therefore the authors of the methodology decided to develop a Life-cycle Assessment (LCA) database that covers many of the building technologies conventionally used in buildings (Bragança et al, 2008b). Nevertheless, since the LCA did not cover all building technologies used in the assessed building, in this study was necessary to use one external LCA tool (SimaPro).

At the level of the societal performance, the evaluation guide presents the analytical methods that should be used to quantify the parameters.

The economical performance is based in the market value of the dwellings and in their operation costs (costs related to water and energy consumption).

3.2 *Normalization and aggregation of parameters*

The objective of the normalization 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 uses the Diaz-Balteiro et al. (2004) equation (Equation 1).

$$\overline{P_i} = \frac{P_i - P_{*i}}{P_i^* - P_{*i}} \forall_i \tag{1}$$

In this equation, $P_i$ is the value of $i^{th}$ parameter. $P^*_i$ and $P_{*i}$ are the best and worst value of the $i^{th}$ sustainable parameter. The best value of a parameter represents the best practice 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 between best and conventional practices 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".

In order to facilitate the interpretation of results, the normalized values of each parameter are converted in a graded scale, as presented in Table 4.

Table 2: Conversion of the quantitative normalized parameters into a qualitative graded scale.

| Grade | Values |
|---|---|
| A+ (Above best practice) | $\overline{P_i} > 1{,}00$ |
| A | $0{,}70 < \overline{P_i} \leq 1{,}00$ |
| B | $0{,}40 < \overline{P_i} \leq 0{,}70$ |
| C | $0{,}10 < \overline{P_i} \leq 0{,}40$ |
| D (Conventional practice) | $0{,}00 < \overline{P_i} \leq 0{,}10$ |
| E (Bellow conventional) | $\overline{P_i} \leq 0{,}00$ |

The aggregation consists on a weighted average of the indicators into categories and the categories into dimensions in order to obtain three single indicators. These three values are obtained using the equation (2) and the final result gives the performance of the building at the level of each sustainability dimension.

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

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.

In the definition of the environmental indicators' weights the methodology uses the US Environmental Protection Agency's Science Advisory Board study (TRACI) and the societal weights are base on studies that were carried out in the Portuguese population (Bragança et al, 2008a).

3.3 *Global assessment*

The last step of the methodology is to calculate the sustainable score (SS). The SS is a single index that represents the global sustainability performance of the building, and it is evaluated using the equation (3).

$$SS = w_E x I_E + W_S x I_S + W_C x I_C \tag{3}$$

Where, *SS* is the sustainability score, $I_i$ is the performance at the level of the dimension *i* and $w_j$ is the weight of the dimension $j^{th}$.

Table 3 presents the weight of each sustainable solution in the assessment of the global performance.

Table 3: Weight of each sustainability dimension on the methodology SBTool$^{PT}$ – H.

| Dimension | Weight (%) |
|---|---|
| Environmental | 40 |
| Societal | 30 |
| Economy | 30 |

Normally, the majority of the stakeholders would like to see a single, graded scale measure representing the overall building score. Such score should be easily for building occupants to understand and interpret but also one which clients, designers and other stakeholders can work with. However, due to the possible compensation between categories, in the SBTool$^{PT}$ approach the global performance of a building is not communicated using only the overall score. The performance of a building is measured against each category, sustainable dimension and global score (sustainable score) and is ranked on a scale from A+ to E

## 4 RESULTS

### 4.1 *Performance at the level of each sustainability category and dimension*

Table 4 presents the values obtained in the assessment of the performance at the level of each sustainability category and dimension. Analysing the results it is possible to verify that all priorities adopted by the project team (described above) were recognised by the SBTool$^{PT}$ methodology and therefore almost all categories (except one) have a performance grade above the conventional practice. The analysed building is only worst than the conventional practice in the category C1 “Climate change and outdoor air quality”. This situation results from the fact that the building uses solid clay bricks on the exterior cladding (one material with greater embodied environmental impacts than the conventionally used materials). In compensation, building is above the best practice’s benchmarks at the level of three categories: C5 “Water efficiency”, C8 “Awareness and education for sustainability”, C9 “Life-cycle costs”. The good performance at the level of the water efficiency is mainly influenced by the implementation of the rainwater harvesting system; the good performance on category C8 is because all dwelling have a complete user manual that guides the inhabitants for the sustainable management of it; and the good economy performance is quite dependable on the lower market price of the dwellings (20% lower than average local’s market practice).

Table 4: Results obtained from the SBTool$^{PT}$ – H for each sustainability category and dimension.

| Dimension | Category | Performance (normalized value) | Performance (qualitative value) | Weight (%) | Dimension Performance ($I_A$) |
|---|---|---|---|---|---|
| Environmental | C1 | -0,20 | E | 13 | B |
| | C2 | 0,56 | B | 20 | |
| | C3 | 0,72 | A | 32 | |
| | C4 | 0,10 | D | 29 | |
| | C5 | 1,03 | A+ | 6 | |
| Societal | C6 | 0,60 | B | 60 | B |
| | C7 | 0,74 | A | 30 | |
| | C8 | 1,13 | A+ | 10 | |
| Economy | C9 | 1,20 | A+ | 100 | A+ |

### 4.2 *Global assessment*

Table 5 resumes the obtained results at the level of each dimension of the sustainable development and the global performance (Sustainable Score). According to the results this building has an A grade, which means that it is considered the best practice in the Portuguese context.

Table 5: Results obtained from the $SBTool^{PT}$ – H for the global assessment.

| Dimension | Performance (normalized value) | Performance (qualitative value) | Weight (%) | Sustainable Score (SS) |
|---|---|---|---|---|
| Environmental | 0,41 | B | 40 | A |
| Societal | 0,69 | B | 30 | |
| Economy | 1,20 | A+ | 30 | |

## 5 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). The sustainable design searches for higher compatibility between the artificial and the natural environments without compromising the functional requirements of the buildings and the associated costs.

The actual environmental, societal and economy context shows that he case for creating sustainable affordable housing is substantial. The presented case-study showed that even with little increase on capital costs (9%) it is possible to design a building with a good level of sustainability, even in cooperative housing (dwellings' price was 20% lower than the local conventional prices). Being this pilot-project nationally and internationally recognized has a good sustainability practice it is possible to conclude that the SBTool – H is well adapted to the Portuguese's environmental, societal and economy contexts.

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