SUSTAINABILITY MULTI-CRITERIA ANALYSIS METHOD – REAL ESTATE ASSESSMENT TOOL FOR A SUSTAINABLE REFURBISHMENT

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Summary

Tools to measure and assess sustainability of buildings are becoming every day more important, especially in Europe where Real Estate is characterized by a great amount of buildings constructed more or less in the sixties, with really low performances. Researches prove that refurbishment interventions simply improving performances of the built environment do not guarantee sustainable results. This work aim to create a multi-criteria design method able to collect all the existent instruments for sustainability assessment from the Environmental, Economic and Social point of view, as written in the definition of sustainability in the EN 15643 (2011), and to apply it to refurbishment of existing buildings. Measurements of sustainability of project alternatives are currently made by the evaluation, using the correct instruments, of some parameters, according to the existing legislation. The output of this system, obtained combining the above-mentioned parameters, is a ranking of the most sustainable project alternatives, with the purpose to help the designer in the selection of the most suitable one. The method, called SMCAM, is created in a way that allows evaluating interventions on construction, on services and on any combination of those, to get the best solution.

The method is inspired by the existent AHP comparison method and includes a weighting system able to weight all the entities of the hierarchic scale of sustainability. The SMCAM method has been applied to two case studies appositely selected: an existent university building in Milan (which is the case study of this proceeding), and a new construction building, designated to be an hospital and situated in the South of France.

Keywords: sustainability, multi-criteria, AHP, real estate, refurbishment

1 Introduction

The aim is to treat sustainability in construction in an engineering way; thus to choose the project alternative that best fits the objectives means the evaluation of parameters describing the whole behaviour of a building during its entire life cycle. This was done in combination with BIM techniques, which really helped first in the survey of the case studies and then in the management of the various project alternatives. The increasing complexity of building technology implies that the best solution could be obtained with a large number of combinations of project options: a good designer could exclude in advance lots of them but many alternatives remain and a BIM model is a good tool for their management.

The main objective of this research is the implementation of a tool able to help the designer during the decision phase; this system should be smart, flexible and user-friendly, otherwise it would bring more efforts than benefits. Another important objective is the definition of the most important parameters assessing sustainability, through a survey done with a pairwise comparison system with the AHP method.

2 Sustainability Multi-Criteria Analysis Method (SMCAM)

A Multi-Criteria Method was chosen to collect existing instruments for (environmental, economic and social) sustainability assessment and also for performance evaluation of project alternatives. To assess the sustainability of a project alternative means to evaluate some benchmarks such as: whole life-cycle costs for the economic sustainability; embodied energy, greenhouse gas emissions, thermal and electric energy demand for the environmental one; thermal comfort, speed and air quality, acoustic comfort and illumination level for the social sustainability. The number of parameters should be established in connection with the analysed interventions. The output of the presented method is a ranking of the most sustainable project alternatives, with the aim to help the designer in the selection of the most suitable one. The method, called SMCAM (*Sustainability Multi-Criteria Analysis Method*) is created in such a way that it allows evaluating interventions of different categories, moreover one alternative does not have to exclude the others and it is possible to evaluate combination of different alternatives to get the best solution in terms of sustainability. A large amount of parameters has been evaluated, starting from International Standards, as instance the EN 15804 (2011) and other research projects with the same theme, like Open House (2011). All these parameters are divided into three major categories according to the EN 15643 (2010). In this study the social sustainability has been converted into the internal performance, measured in terms of internal comfort perceived by the occupants.

2.1 Parameters and Hierarchic scale

For the environmental assessment of sustainability five parameters have been chosen, starting from the analysis of the building compulsory and voluntary requirements. They have been divided in two subcategories: environmental impact and resources consumption:

- CO_2 emissions [kg CO_2 equivalent]
- embodied energy [MJ]
- primary energy consumption [kWh/m^2 y]
- energy consumption [kWh]
- water consumption [m^3]

The parameters used for the economic assessment are those that, assembled together, give the entire cost on the life cycle of a building, as in the ASTM E917-05 (2010). The disposal cost has not been considered in this research because of two main reasons: the great uncertainty in its calculation (the disposal cost will occur at the end of the life cycle of a building, in our case study 60 years) and its low influence, as showed by the results of a sensitivity analysis; so the effort to add the evaluation of the disposal cost could not give better and more accurate results.

- initial cost [€]
- operational cost (primary energy) [€]
- operational cost (energy and materials) [€]
- maintenance cost [€]

The internal performance has been evaluated through the assessment of five main parameters related with the internal comfort:

- winter internal comfort [degreehours]
- summer internal comfort [degreehours]
- internal acoustic comfort [dB]
- IAQ Internal Air Quality [PPD]
- internal visual comfort [PPD]

All the fourteen parameters can be seen in the Fig. 1. The method is built according to the AHP selection process as shown in Kaklauskas, Zavadskas, Raslanas (2005) and in Sonmez, Ontepeli (2009).

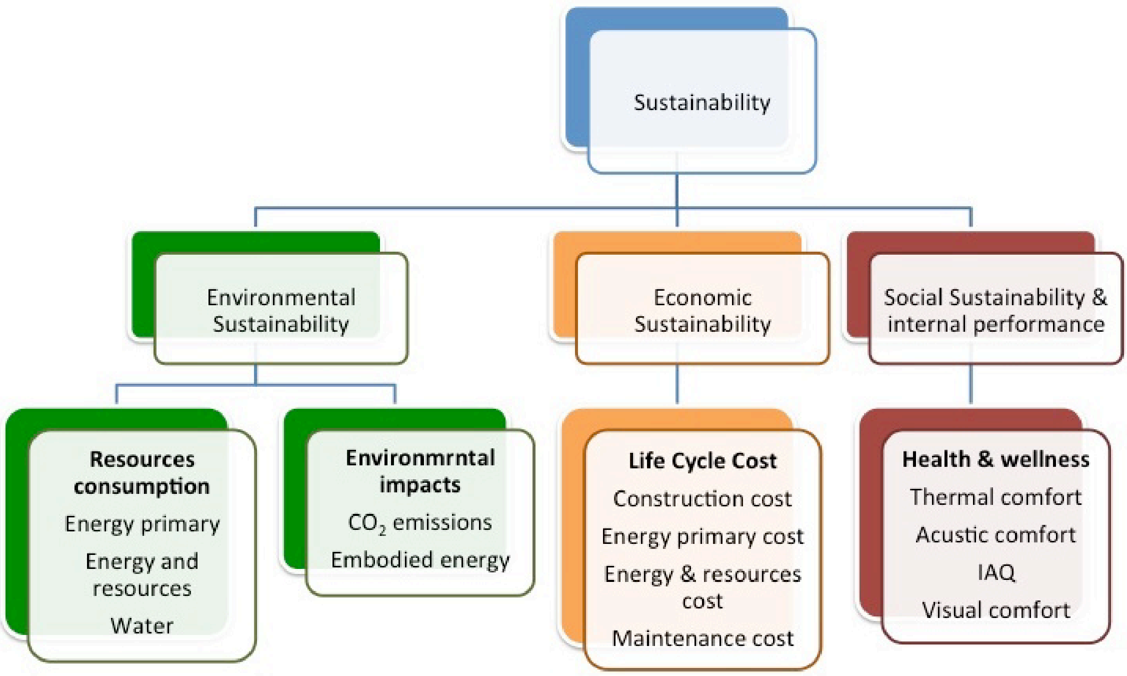

Fig. 1 *Hierarchic scale of the SMCAM method*

The first phase consists in the creation of the hierarchic scale, made by three levels and reported in Fig. 1. The project alternatives are in the bottom of the hierarchic scale, out of the three levels. It is important to notice that this hierarchic scale can be easily modified by inserting or deleting one or more parameter; this because the SMCAM tool has been created with the idea of following the evolution of laws and researches, so it is not a static instrument but a dynamic one.

2.2 Standardization

The evaluation of different parameters with different units of measure and magnitude requires a standardization process, which can be obviously made in many different ways. In this study different approaches have been tested starting from Zavadskas, Turksis (2008) and then the standardization method with equally distributed scale has been used, both for parameters that need to be maximized and for the one that have to be minimized. This process seems to be really effective because it standardizes the parameters giving as result 1 for the best solution and 0 for the worst one; this simplifies the entire process of selection, avoiding misunderstanding and errors. The formulas used are presented below.

$$r_{ij} = \frac{x_j^{max} - x_{ij}}{x_j^{max} - x_j^{min}} \tag{1}$$

$$r_{ij} = \frac{x_{ij} - x_j^{min}}{x_j^{max} - x_j^{min}} \tag{2}$$

Where x is the parameter that has to be standardized, *min* and *max* are referred to the set of alternatives that have to be evaluated through the system and r is the standardized value of the parameter.

The equation (1) has to be used for the parameters that need maximization, while the equation (2) has to be used for the ones that need minimization.

The system standardizes the parameters automatically while the user inserts his data; the only requirement needed is the insertion of the *max/min* criteria for the parameters, as instance the costs should be minimized and the revenues, if present, should be maximized.

2.3 Parameters pairwise comparison

In this method a weighting system able to consider the (desired) relative importance of parameters on sustainability seemed to be convenient, otherwise all the parameters will have the same importance, and this is not true; therefore a pairwise comparison among the elements of the second and third level of the hierarchic scale was conducted. The comparison was performed among elements of the same category (the three fields of sustainability) to get three series of weights. First of all, the relative importance of the field of sustainability has been calculated, with the following results:

- environmental sustainability 55 %
- economical sustainability 21 %
- internal performance 24 %

Then the relative importance of the parameters listed above has been calculated with the same method. The results are shown in the Tab. 1 and in the Fig. 2.

Tab. 1 *Relative importance of the parameters (three fields)*

Parameter	Weight	Parameter	Weight
ENV_Primary energy consumption	37 %	ECO_Energy and resources cost	19 %
ENV_ Energy and resources consumption	23 %	ECO_Maintenance cost	12 %
ENV_Water consumption	16 %	ECO_Disposal cost (not used)	0 %
ENV_CO_2 emissions	13 %	PERF_Thermal comfort	46 %
ENV_Embodied energy	11 %	PERF_Acoustic comfort	24 %
ECO_Construction cost	39 %	PERF_Internal Air Quality	19 %
ECO_Primary energy cost	30 %	PERF_Internal visual comfort	11 %

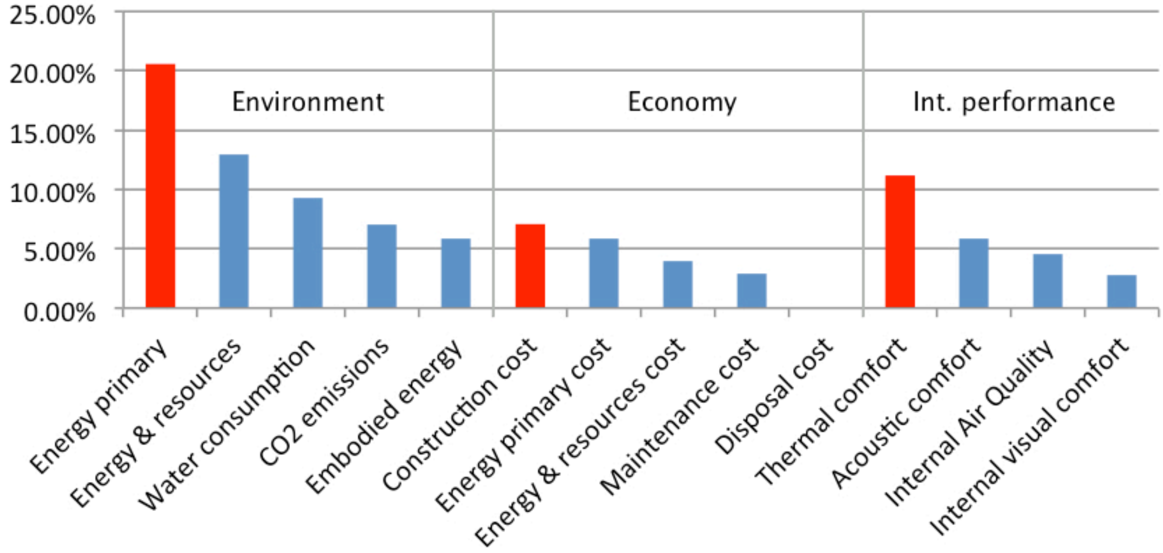

Fig. 2 *Relative importance of the parameters (global sustainability)*

The evaluation of the parameters was carried on by an online survey sent to a great amount of people consisting mainly of professionals, professors and students of Architecture and Engineering; totally 62 answers have been collected. First of all the data gathered have been analysed together to get the minimum, the maximum and the average, which was used as score describing the related parameter.

These scores have been inserted into a comparison matrix and with a process that involves eigenvectors and eigenvalues the relative importance was carried out. The list of weights can be easily updated following new studies on sustainability and it can be also adapted to case study, in relation to specific necessities of the customer. Otherwise this list of weights can be used for all the case studies, even if the one or more parameters are excluded from the evaluation, without making again the pairwise comparison.

2.4 Output

After the pairwise comparison for the parameters weights assessment, project alternatives can be analysed with the SMCAM method. This last phase is the easiest from the mathematical point of view but it requires a strong reasoning. First of all the values describing each alternative, previously standardized according to their criteria (minimization or maximization), have to be multiplied for their weights and then they can be sorted into totally four lists, three for the secondary objectives (environment, economy and society: each alternative has a partial score, which is the weighted average of the standardized parameters of just one field of sustainability (3)) and a final one with the global sustainability (each alternative has a final score made as a weighted average of the three partial previous results (4)), which is the primary objective.

$$S_i = \sum_{j=1}^{n} P_j * W_j \tag{3}$$

$$S = \sum_{i=1}^{3} S_i * W_i \tag{4}$$

Where i means environment, economy and internal performance and W is the weight the parameters (3) and of the three sustainability fields (4). P is the standardized value of the parameter. These four lists can be called *sustainability rankings of the alternatives*. This tool can also be used in an iterative way: at first it may help in the selection among a lot of project alternatives and then a second round can be done with just a small group of possibilities or the aggregation of more solutions in one. Another interesting way to use this tool in the real estate field, is to use it to evaluate the entire building, by comparing the actual state with a different scenario, calculating at the end a refurbishment potential.

The method really helps in the decision phase because it allows the comparison both at the third and the second level of the hierarchic scale; so the user can compare both the final and the partial rankings to better understand which solution fits best the objectives.

3 Case Study

The case study expressly selected to test the SMCAM method consists of a building of the Leonardo Campus of the Politecnico di Milano, in Milan – Italy. The building is composed by two connected bodies, one with 5 storeys of classrooms and the other with offices and labs distributed on 8 storeys (Fig. 3).

Fig. 3 *Building "Nave" Politecnico di Milano*

It has been built in the sixties so the main (the most interesting for this work) technologies are:

- slabs in concrete;
- pillars and beams both in concrete and steel;
- opaque envelope composed by a double layer of bricks with an air gap in the middle, no insulation;
- windows with one glazing and steel frame without thermal cut;
- plane roof without thermal insulation;
- heating system with radiators in the classrooms;
- heating and cooling system with fan-coils in the offices.

3.1 Building survey

The building survey was done by filling diagnostic forms describing all the components, both construction and plants. Totally 58 elements have been evaluated and some criticalities came out from this work: there are many anomalies in the windows and in the external finishing of the envelope; furthermore the analysed plants (heating and electric), despite the lack of serious anomalies, are characterized by obsolete components and they do not entirely respond to the current requirements, because their Reference Service Life RSL, ISO 15686-1 (2000) has been exceeded. The building actual condition is not so much critic but problems have been encountered during the survey:

- performances of the windows are really low;
- external finishing is locally detaching;
- glass bricks in the classrooms area are seriously deteriorated;
- same deterioration for the fibrocement boards in the offices zone;
- plants are working but they do not really satisfy the current requirements since they are quite old and not well calibrated, as instance:
    - there is no zone regulation of the heating system, there is just a regulation based on the external temperature, which is no more sufficient for a good level of internal comfort;
    - distribution of the radiators is not well organised: there are too many radiators in the corridors and in other spaces without presence of people;
    - efficiency of the heating system is really low;
    - illumination has manual on/off commands and during the night is frequently turned on.

3.2 Project alternatives selection

Following the survey of the current state of the building, 44 project alternatives have been evaluated to get the best refurbishment solution in terms of sustainability. These possible solutions have been designed to solve the above-mentioned major criticalities on envelope, both opaque and transparent, roof, heating, cooling and electric plants. These interventions have been studied because this building is part of a refurbishment program inside the bigger project "Campus Sostenibile – Città Studi" and there is the possibility to concretely implement them. For each one, all the fourteen parameters described above have been calculated with different techniques, depending on the data available. A BIM model of the entire building has been created to easily manage the refurbishment possibilities and their related data (Fig. 4).

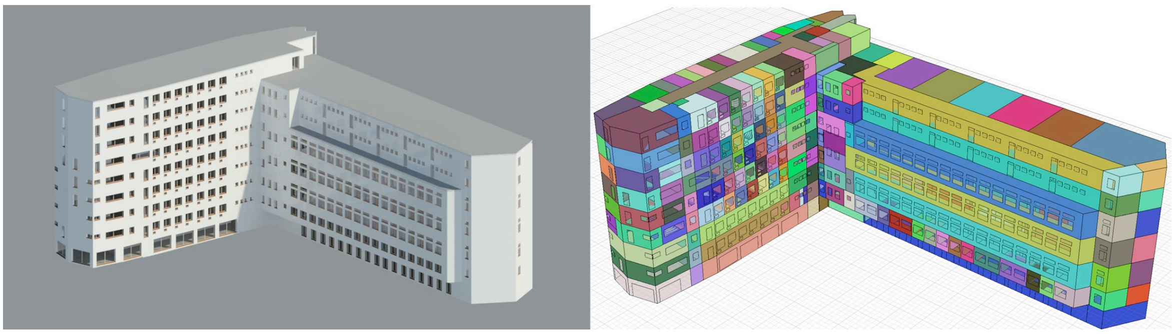

Fig. 4 *BIM models of the case study*

Depending on the information required, two models have been used, the first is architectonical and contains information about spaces, zones and quantities; the second is more technical and contains data about components stratigraphy, time schedules, insulation levels and all the information required for the calculation of the parameters.

After the calculation of all parameters they have been standardized and weighted to get the rankings, which can be seen as *sustainability indexes of the alternatives*. These indexes could be partial (connected to just one branch of sustainability) or comprehensive of all the three major fields. Five alternatives have been selected according to these criteria: the most sustainable alternatives overall and the necessary alternatives (which means the alternatives connected to components with really low performances, not depending on the improvement of sustainability). The selected alternatives are listed in the Tab. 2 and also plotted in a chart (Fig. 5).

Tab. 2 *Sustainability indexes for the selected alternatives*

#	Component	Code	Env. S.	Eco. S.	Int. Perf.	Sustainability
1	Windows	A.01	0.3647	0.1251	0.0838	0.5737
2	Illumination	A.02	0.3728	0.1481	0.0471	0.5681
3	Heating system	A.03	0.2515	0.1430	0.0192	0.4138
4	Fibrocement boards	A.04	0.1844	0.1285	0.0192	0.322
5	Glass bricks	A.05	0.1788	0.1269	0.0192	0.3250

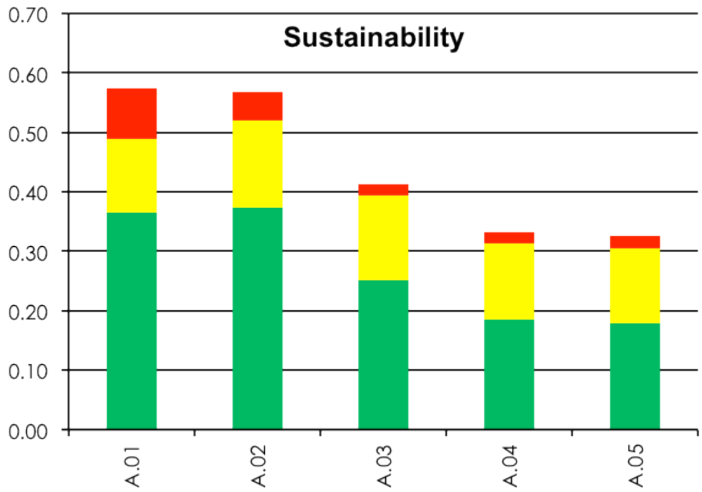

Fig. 5 *Project alternatives final ranking*

The values have been calculated starting from the parameters values, which have been standardized with (1) and (2) and then ranked (weighted and averaged) with (3) and (4).

The table above shows the alternatives ordered with descendent sustainability index (the bigger is the value the better is the alternative). The first three alternatives bring serious improvements to the building; on the other hand, the last two are necessary because the fibrocement boards and the glass bricks show really low performances and they require prompt replacement.

The five alternatives have been aggregated to make a final comparison with the current situation of the building. The fourteen parameters have been recalculated without using the SMCAM method, because this phase is aimed at checking the solution. The Tab. 3 shows a large performance increase in terms of environment and economy, and also a good upgrade in the internal performance level. The initial cost is obviously high but the five selected interventions could be distributed during many years.

Tab. 3 *Comparison with the actual situation*

Parameter	**Current State**	**Selected Alternatives**	**Δ [%]**
EP_H [kWh_{term}/m^2 y]	141.59	33.55	-76.31 %
EP_C [kWh_{term}/m^2 y]	36.15	33.6	-7.06 %
Electricity [kWh_{elet}/m^2 y]	63.94	52.43	-18.00 %
CO_2 [kg CO_2/m^2 y]	45.15	27.04	-40.11 %
EE [MJ/m^2]	1,137	1,399	23.07 %
Initial COST [€]	0	604,882	-
Maintenance Cost [€]	2,774,435	2,492,588	-10.16 %
EPH Cost [€]	2,433,234	576,534	-76.31 %
EPC Cost [€]	299,687	278,535	-7.06 %
Electricity Cost [€]	2,955,131	2,423,208	-18.00 %
LCC [€]	8,690,734	6,375,746	-24.66 %
Thermal Comfort [dh summer]	97,147	103,869	6.47 %
Thermal Comfort [dh winter]	404,564	385,182	-5.03 %
Acoustic Comfort [dB]	39.33	45.21	-13.01 %
IAQ [PPD]	54.90 %	54.90 %	0.00 %
Visual Comfort [PPD]	30 %	10 %	-66.67 %

The sustainability index of the building, thanks to the five alternatives selected, goes from 0.2121 to 0.7155, which means an improvement of the building sustainability of the 70.36 %, obviously according to the weights and the criteria used during these assessments.

The sustainability indexes have been calculated as previously explained. The final comparison was done with only two alternatives: the current state and the five refurbishment alternatives aggregated in just one option. The same formulas explained before have been used in this final phase.

This case study is part of the bigger project "Campus Sostenibile – Città Studi" that is aimed at refurbishing the Campus and making it more sustainable. The good piece of news is that two of the previously analysed alternatives (windows replacement and implementation of the illumination system) are actually in the construction phase. The other alternatives will be evaluated in the next months.

4 Conclusions

There are too many ways to assess sustainability and there are lots of instruments and maybe tools better than this, but its simplicity and flexibility make SMCAM a useful instrument, ready to be used both during the pre-design and design phases or during the dialog technician-user.

The possibility to add parameters and modify weights during the analysis is useful because it can help in organizing the project alternatives by collecting data.

Further developments could involve a system able to guide the survey of the building, also in combination with emergency interventions, not strictly related to sustainability, but required to bring back the building to the minimum level of performance.

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