Comparative assessment of exterior walls construction solutions' sustainability

L. Bragança & R. Mateus
University of Minho, Department of Civil Engineering, Guimarães, Portugal

ABSTRACT: In this document a methodology for the comparative sustainability assessment of construction solutions will be approached. This work intends to be a contribution for the Construction in order to turn this industry more compatible with the sustainable development aims. The presented methodology will be applied to some conventional and non-conventional exterior walls construction solutions in order to find, inside the sample, the most sustainable solution.

1 INTRODUCTION

Construction industry is one of the most important European economical sectors, but it still relies too much on traditional construction methods and unskilled handwork, being characterized by an excessive use of natural resources and energy. This implies great environmental, social and economical impacts that could easily be reduced. This industry, in general, and the buildings sector in particular, contributes to the degradation of the environment through the dilapidation of natural resources. Building construction consumes 40% of the raw stone, gravel, and sand globally used each year, and 25% of the virgin wood. Building also account for 40% of the energy and 16% of the water annually used worldwide (Roodman, 1995). This reality is incompatible with the sustainable development aims that seek the balance between the environmental, economic and social dimensions.

One of the possible solutions for this problem is the use of building technologies more compatible with the environmental balance. In the last years, even with a small impact, an evolution in this domain has been observed, and now there are new materials and construction solutions more sustainable than the conventional ones. The Project Team, mainly during the Design Phase, has the biggest responsibilities in selecting technologies with high eco-efficient materials content. This kind of materials has low environmental impact during its live cycle, without committing the necessary functional performance for the construction element and the final product economical viability.

In the majority of the less developed countries, this subject is still very recent. In these countries, the biggest part of the construction companies and the population in general, are not sufficiently informed about the individual and collective advantages of the "Sustainable Construction" concept. In the developed countries, this subjective is no more an environmentalist's exclusive flag, being nowadays one of the most important aspects in the construction's global quality assessment.

In the construction market the number products with the sustainable label is increasing, without any kind of control. So, some of those solutions could not present any advantages relatively to the conventional. The sustainable label is adopted in a way to increase sales. Consequently is urgent the development and application of methodologies that could help the design teams in choosing construction solutions that turns the construction's future more sustainable.

2 SUSTAINABLE ASSESSMENT METHODOLOGIES

In the solutions' sustainability assessment, several parameters could be analyzed, some of them not correlated and/or not expressed in the same units. On the other hand, the way that each parameter influences the sustainability is neither consensual nor unalterable along the time. So, it is difficult to express a solution's sustainability in absolute terms, through an indicator that integrates all of the analyzed parameters and that allows the quantitative classification of its sustainability. For example, a solution with good environmental performance but without the minimum functional requirements could not be considered sustainable. On the other hand, a solution with good environmental and functional performances, but with much higher life-cycle costs than the conventional one, could not be considered sustainable, because the prohibitive costs are a barrier for its implementation.

The sustainability is a relative subject that should be assessed comparatively and relatively to the most widely used solution – conventional /reference solution – in a certain country/local. This way, comparing each of the selected sustainability indicators it is possible to verify, at the level of each one, if the solution in analysis is better or worse than the conventional one. The most sustainable solution depends on the technological limit of each moment.

In a construction solution sustainability assessment process, the first step consists in gathering the most relevant functional and technical data about the construction solution. The second step consists in selecting an appropriate method that allows the quantitatively assessment of the sustainability. The methodology to adopt should be simple and flexible, to conveniently help the design teams in choosing a certain technology in detriment of others less sustainable.

In certain developed countries, some systems and tools for the sustainability assessment are being implemented or in the development phase. The most important are: Building Research Establishment Environmental Assessment Method (BREEAM), Leadership in Energy & Environmental Design (LEED) and Green Building Challenge (GBTool).

The presented methodologies aim the evaluation of the global sustainability of a building. Its application is complex and needs the previous knowledge of some data. Some of the sustainability assessment tools have datasheets that gather some of the needed data, although the data is related with the particular aspects of the country of origin, which turns its application in a different country very difficult. These systems focus mainly the building environmental impact assessment in a global perspective. The sustainability of the construction solutions is one of the analyzed aspects in the buildings' global sustainability assessment.

In this perspective and for the propose of this work a methodology named Methodology for the Relative Assessment of the Construction Solutions Sustainability (MARS-SC), is presented (Mateus, 2004).

2.1 *Methodology for the relative assessment of the construction solutions sustainability (MARS-SC)*

In the MARS-SC the assessment of the sustainability is accomplished relatively to the most applied solution – conventional/reference solution – in a certain place. In this methodology three groups of indicators are approached: environmental, functional and economical. The methodology follows the following steps:

1st Step) Defining the indicators to be evaluated on each group. The number of indicators analyzed on each group can be adjusted depending on the specific characteristics of the construction solution, on its functional demands, on the evaluation objectives and on the available data. Table 1 shows some of the most important parameters that could be analyzed in this methodology.

2nd Step) Calculating the comparison indexes. The comparison between the solution under analysis and the reference solution is accomplished at the level of each parameter through a comparison between indexes. These indexes express the relationship between the value of a certain indicator in the solution under analysis and the same parameter in the conventional solution that allows verifying, relatively to each analyzed parameter, if the solution is better or worse than the conventional construction solution. The indexes are calculated by the equation 1:

$$I_X = \frac{V_X}{V'_X} \tag{1}$$

where I_x = index of the indicator x; V_x = value of the indicator x in the solution in analysis; and $V'x$ = Value of the indicator x in the conventional solution.

Table 1. Indicators that can be analyzed in the MARS-SC methodology.

Indicators		
Environmental	Functional	Economical
Global warming potential (GWP)	Air born sound insulation	Construction cost
Primary energy consumption (PEC)	Percussion sound insulation	Utilization cost
Recycled content	Thermal insulation	Rehabilitation cost
Recycling potential	Durability	Demolition cost
Raw material's reserves	Fire resistance	Residual valor
Eutrophication potential	Flexibility of use	End use treatment cost

3rd Step) Giving a score for each indicator. Through the indexes value the score of each indicator (N_i) is defined, in a scale of values between -3 and 3. If the score is negative, the solution in analysis is worse than the conventional one, at the level of that indicator. Otherwise the solution in analysis is better than the conventional one. The score is given through the table 2.

Table 2. Indicators score (Ni) through the value of the comparison indexes (Ix).

I_x	Score (N_i)
≤0.6	3
]0.6;0.8]	2
]0.8;1.0[	1
1.0	0
]1.0;1.2[	-1
]1.2;1.4]	-2
≥1.4	-3

4th Step) Graphical representation of each indicator's score (Sustainable Profile). The indicators' scores are represented in a radar type graphic with a number of rays equal to the number of indicators in analysis.

5th Step) Determining the solution's Performance Scores at the level of each group of indicators (ND_i). The solution's performance is evaluated inside each group of parameters, through equations 2 to 5. With the ND_i it is possible to synthesize in one value the solution's performance inside each group.

$$ND_A = \sum_{i=1}^{m} WA_i x NIA_i \tag{2}$$

$$ND_F = \sum_{i=1}^{n} WF_i x NIF_i \tag{3}$$

$$ND_E = \sum_{i=1}^{o} WE_i x NIE_i \tag{4}$$

$$\sum_{i=1}^{m} WA_i = \sum_{i=1}^{n} WA_i = \sum_{i=1}^{o} WA_i = 1 \tag{5}$$

where ND_A = environmental performance's score; ND_F = functional performance's score; ND_E = economical performance's score; WA_i = environmental indicator (i) weighting factor; WF_i = functional indicator (i) weighting factor; WE_i = economical indicator (i) weighting factor; m = number of environmental indicators in study; n = number of functional indicators in study; o =

number of economical indicators in study; NIA_i = environmental indicator (i) score; NIF_i = functional indicator (i) score; NIE_i = economical indicator (i) score.

The weighting factor of each indicator in the determination of the three performance scores is not consensual.
At the level of the environmental indicators there are some studies which allow the almost consensual definition of its weights. The most important were the studies performed by the United States Environmental Protection Agency (EPA). EPA's studies identified, for a list of twelve environmental indicators, the relative importance of each one among the others through their environmental effects (EPA, 1990). In the MARS-SC the weighting factors presented in that study are used directly or by extrapolation.
There are no studies about the functional indicators. So, it is considered an equal weight distribution per each indicator. The use of more consensual values could be possible by the application of a Multiattribute Decision Analysis methodology.
In the economical indicators domain, considering that the biggest part of the construction solution's life cycle is related to the use phase, it is suggested that the maintaining and operational costs should have bigger weighting factors than, for example, the construction costs, in the economical performance assessment.

6th Step) Sustainable Score (NS) calculation. Using Equation 6 it is possible to synthesize in on value the solution's performance at the level of the three vectors considered in the sustainability assessment.

$$NS = W_1 xND_A + W_2 xND_F + W_3 xND_E \quad (6)$$

where NS = solution's sustainable score; W_1 = environmental indicators group's weighting factor; W_2 = functional indicators group's weighting factor; W_3 = economical indicators group's weighting factor.

The way that each indicators group influences the sustainability is not consensual. Although, aiming a bigger compatibility between the artificial environment and the natural one without forgetting the functional requirements of the construction solutions, it is current the use of bigger weights for the environmental and functional groups. In this way, in the MARS-SC is used the following distribution of weights: $W_1 = 0.40$; $W_2 = 0.40$; $W_3 = 0.20$.
Consulting Table 3 and considering the NS it is possible to classify the construction solution's relative sustainability.

Table 3. Construction solution's sustainability classification.

NS	Sustainability classification
<-1	Mediocre
[-1,-0[	Unsatisfactory
0	Reference
]0,1[	Better
[1,2[	Good
[2,3]	Very good
3	Excellent

3 COMPARATIVE ASSESSMENT OF EXTERIOR WALLS CONSTRUCTION SOLUTIONS'SUSTAINABILITY

3.1 *Used methodology*

The Methodology for the Relative Assessment of the Construction Solutions Sustainability (MARS-SC) is used in the performed evaluation. The sustainability is evaluated, relatively to the conventional solution, through the comparison of two environmental parameters (global warming potential -GWP- and primary energy consumption -PEC-), three functional (air born sound insulation -Dn,w-, thermal insulation -U- and wall's thickness –WT-) and one economical (construction cost –CC-). The weighting factors considered in the Performance Scores (ND_i) and in the Sustainable Score (SS) calculation are in Table 4.

Table 4. Weighting factors considered in the assessment.

Group	Indicator	Indicator's weighting factor	Group's weighting factor
Environmental	GWP	0.75	0.40
	PEC	0.25	
Functional	$D_{n,w}$	0.33	0.40
	U	0.33	
	WT	0.33	
Economical	CC	1.00	0.20

3.2 *Construction solution's characterization*

The conventional/reference solution (wall 1) is one of the most applied technologies in exterior walls in Portugal. The solution is a double (15+11 cm) hollow brick wall with a 2 cm thick extruded polystyrene (XPS) layer placed on the air gap. Each surface of the wall is covered by a 1,5cm thick layer of render.

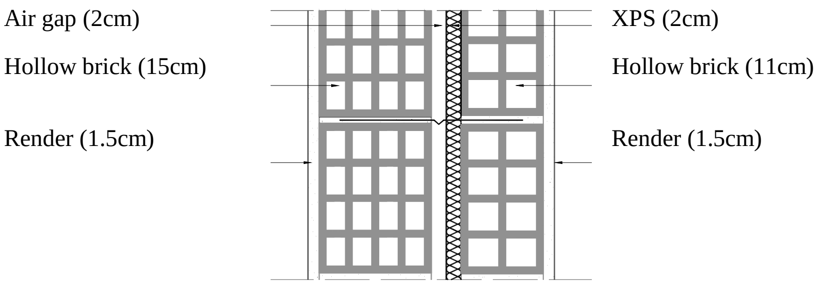


Figure 1. Conventional/reference solution (Wall 1).

Besides the conventional solution, more three construction solutions were analyzed.
Having in mind the biggest relative importance of the thermal behaviour towards the other functional requirements, the construction solutions were defined in a way that their thermal behaviour was, in minimum, equal.
The other analyzed construction solutions were:

Wall 2) Double pane wall with an exterior stone pane and an interior hollow brick pane (Figure 2).

Wall 3) Single pane wall with external thermal insulation with rendering (Figure 3).

Wall 4) Light gauge steel frame wall (Figure 4).

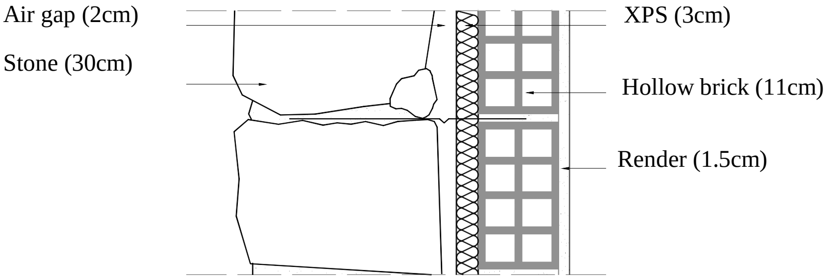


Figure 2. Wall 2 construction solution.

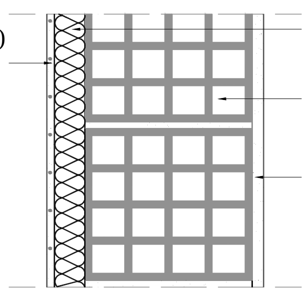


Figure 3. Wall 3 construction solution.

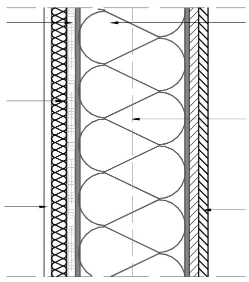


Figure 4. Wall 4 construction solution.

3.3 *Results*

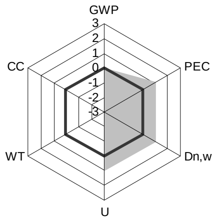
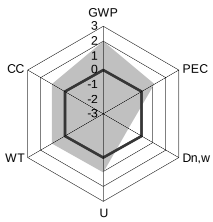
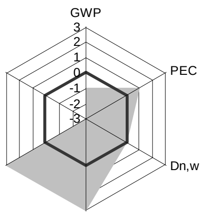
Table 5 resumes the obtained results in the sustainable indicators evaluation. Table 6 resumes, for each construction solution, the performance scores of each indicators group and also the respective sustainable score.

Table 5. Indicators value

Indicator	Wall 1	Wall 2	Wall 3	Wall 4
GWP (g/m^2)	46511	44221	36538	49883
PEC ($k.W.h/m^2$)	197	169	159	171
$D_{n,w}$ (dB)	51	59	49	51
U ($W/m^2.ºC$)	0.70	0.65	0.60	0.23
WT (cm)	33.00	47.50	28.50	19.60
CC (€/m^2)	46.70	125.90	41.80	133.40

Inside the analysed sample and in accordance with the considered indicators, the results shows that the most sustainable solution is the single pane wall with external thermal insulation with rendering (Wall 3) and the less sustainable is the double pane wall with an exterior stone pane and an interior hollow brick pane (Wall 2). The light gauge steel frame wall's (Wall 4) sustainability is similar to the reference solution. At the environmental performance level, Wall 3 is the best solution, while the Wall 4 is the worst. The Wall 4 has the best functional performance and the Wall 2 the worst. Wall 3 has the best economical performance.

Table 6. Sustainability of the construction solutions

Construction solution	Sustainable profile	Performance			Sustainable score (NS)	Relative sustainability
		Env. (ND_A)	Fun. (ND_F)	Econ. (ND_E)		
Wall 2		0.25	0.33	3.00	-0.63	Unsatisfactory
Wall 3		1.75	0.66	1.00	1.16	Superior
Wall 4		-0.50	1.98	3.00	0.00	Reference

4 CONCLUSIONS

The project teams have big responsibilities in searching the sustainability in the building and real estate sectors, through the selection and use of construction solutions with improved environmental, functional and economical performances, during their whole life-cycle. The development and use of sustainability's evaluation methodologies and tools are fundamental aspects for these goals.

Analysing the MARS-SC results, it could be observed that they depend on the type and number of each group's considered indicators and on the relative weight considered for each one. Aiming more consensual results, this methodology should be developed through the pre-definition of a list of indicators for each construction solution.

The presented results and methodology intends to be a contribution to the sustainability in the construction industry domain, through the use of construction solutions with improved environmental, functional and economical performances.

5 REFERENCES

Mateus, Ricardo, 2004. Novas Tecnologias Construtivas Com Vista à Sustentabilidade da Construção. Dissertação de Mestrado, Departamento de Engenharia Civil da Universidade do Minho, Portugal.

United States Environmental Agency (EPA), Science Advisory Board (SAB), 2000. Toward integrated Environmental Decision Making. EPA-SAB-EC-00-011, Washington, D.C..