The Sustainability of a Building Made by using of Recycling Materials

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Abstract: A very important problem encountered all over the world and increasingly widespread in the construction field is represented by sustainability. This paper presents a sustainability study, performed on a building located in Romania - Arad County, which involved the consolidation and expansion of an existing building in order to create an investment with the functionality of an agrotourism guesthouse. The sustainability study involved the calculation of coefficients of the environmental dimension on the basis of which the embodied energy and green house gas emissions GHG were estimated as a result of the selected materials, transportation and equipment used during the process. The social dimension was taken into account by establishing the coefficients that influence visual, acoustic and thermal comfort. Besides the fact that modern construction resulted from the perspective of the materials and equipment used, an important factor represents that, part of the materials that resulted from the partial demolition of the existing construction, were reused.

Key-Words: sustainability, embodied energy, consolidation, existing building, environmental, economic dimension, social criteria, demolition, reused materials

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1 Introduction

In the broadest sense, sustainability means the ability to maintain or support a process continuously over time. In time this notion has become more and more complex, [1].

The most agreed definition is "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs", [2].

Sustainable development has been identified as a top priority problem in construction works. Directives and standards have been developed which are intended to encourage the implementation of sustainable criteria in the life cycle stages of a construction work, [3].

This notion is often broken into three core concepts: environmental protection, social and economic development.

On the other hand, ensuring environmental sustainability is a noble task that civil engineers should pursue, both when preserving or refurbishing structures and designing tomorrow's infrastructure. What engineers design and built today will influence the environment and society for decades to come, [4].

The buildings and buildings construction sectors combined are responsible for almost one-third of total global final energy consumption and nearly 15% of direct CO2 emissions. As seen in Figure.1, direct and indirect emissions from building operations, [5], plummeted to about 9 Gt in 2020, after having risen an average 1% per year since 2010.

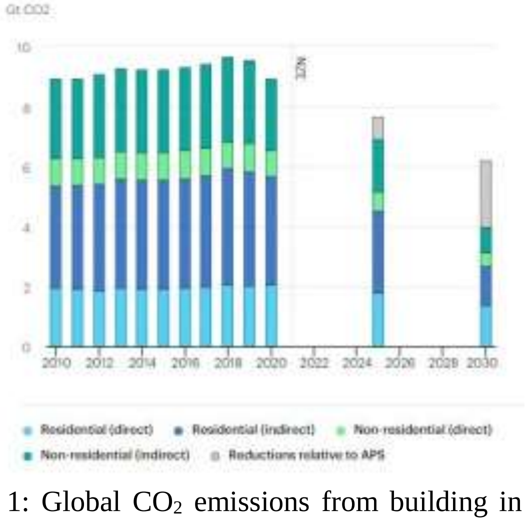

Fig. 1: Global CO_2 emissions from building in the Net Zero Scenarios 2010-2030

The EU aims to be climate-neutral by 2050 - an economy with net-zero greenhouse gas emissions, [6]. Despite the expected rebound in emissions in 2021 being moderated by continued power sector decarbonisation, buildings remain off track to achieve carbon neutrality by 2050. To meet this target, all new buildings and 20% of the existing building stock would need to be zero-carbon-ready as soon as 2030, [7].

2 Sustainability Model

Worldwide, there are more sustainability models. The most well-known are presented in Figure 2, [8].

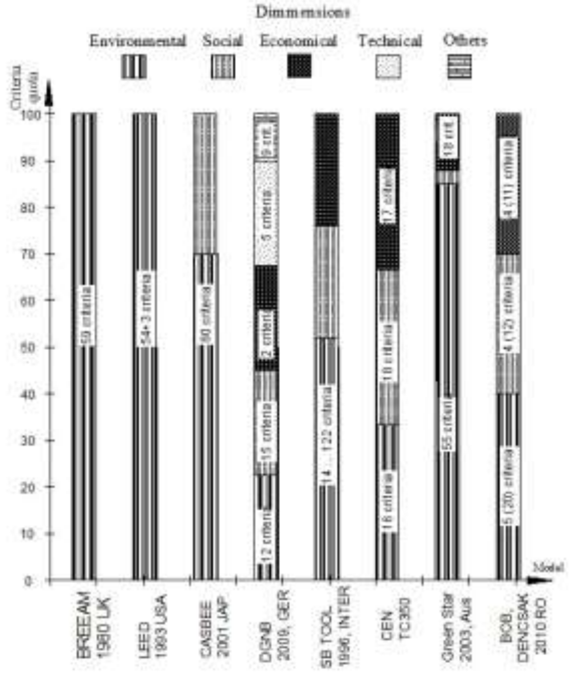

Fig. 2: Sustainability Assessment Methods

Average values of sustainability assessment methods :

$$e_{med} = 0{,}64 \quad ; \quad s_{med} = 0{,}18 \quad ; \quad c_{med} = 0{,}15$$

Average values without including BREAAM and LEED criteria:

$$e^1_{med} = 0{,}46 \quad ; \quad s^1_{med} = 0{,}28 \quad ; \quad c^1_{med} = 0{,}27$$

For the sustainability study, the authors used Bob-Dencsak model. This model is based on 44 parameters, out of which 21 correspond to the environmental dimension, 11 to the economic dimension and 12 to the social dimension.

According to this model for a sustainability index obtained by calculus greater than 4 (80 points) the level of sustainability is very good, for an index between 3 and 4 (60-80 points) is good, for 2-3 (40-60 points) acceptable and for less than 2 (40 points) is insufficient.

The parameters are explained for each criterion as follows:

The environmental criteria

Initial embodied energy (En_1) depends on the embodied energy (EE) in terms of manufacturing the materials, their transport and the equipment or machines used in the construction process.

$$En_1 = \frac{EE \times m}{A \times t} \quad (1)$$

Non-renewable embodied energy during the life cycle of the building (En_2) was calculated in the energy performance certificate according to the annual energy consumption.

Non-renewable embodied energy in construction materials used for maintenance, renovation and replacement works (En_3) and the embodied non-renewable energy in building materials after the end of life (En_4), [9], are calculated with Formula (1) for the related works.

En_5 is estimated depending on the use of renewable energy sources.

Initial green house gas GHG emissions (G_1) are calculated in a similar way as the initial embodied energy, with the difference that the input data, in this case, are the $CO_{2,eq}$ emissions in the manufacturing of the materials, transportation and use of equipment or machines, [10], during the construction process.

$$G_1 = \frac{\mathrm{CO}_{2\,\mathrm{eq}} \times m}{A \times t} \quad (2)$$

GHG emissions during the life-cycle of the building (G_2) were calculated in the energy performance certificate according to the CO_2 equivalent emission index.

GHG emissions from construction materials used for maintenance, renovation and replacement works (G_3) and end of life GHG emissions (G_4) are calculated with Formula (2) for the related works.

Heat island effect of the roof (G_5) is calculated using the Solar Reflectance Index (RI_i) of roofing material and the roof surface (A_i)

$$RI^n = \frac{\sum \mathrm{RI_i} \times A_i}{\sum A_i} \quad (3)$$

The efficiency of the materials used according to the building design is given by the following parameters:

Re-use of existing materials, products and structural elements (MR_1) it is expressed by the ratio between the reused structural area and the total area.

Material efficiency (MR_2) is the total weight of the structure (G) per the entire volume (V) of the building.

$$MR_2 = \frac{G}{V} \quad (4)$$

Use of materials with recycled content (MR_3) it is expressed by the ratio between the weight of recycled materials and the total weight.

Use of local resources (MR_4) is a parameter depending on the transport distance (d_i) of the materials m_{ti}.

$$MR_4 = \frac{\sum m_{ti} \times d_i}{m} \quad (5)$$

In our case, the effects of the works on the construction site are reflected through the waste from the construction site (CS_1), the dust produced on the construction and demolition process stored outside the construction site (CS_2) which is estimated from the protection measures provided in the project and the noises generated in the construction process (CS_3).

$$CS_3 = \frac{\sum L_{si} \times h_i}{h_d} \quad (6)$$

where:

L_{si} - level of sound produced by the equipment
h_i - hours in use of the equipment/machine
h_d - daily number of working hours

Last environmental parameters are for the soil contamination by execution (LW_1), the land used (LW_2) which is the ratio between the built area and the land surface, and water consumption (LW_3).

Water consumption depends on the number of people staying at the guesthouse.

The economic criteria

The initial cost C_1 represents the ratio between the total cost of the construction (including all costs related to the design such as structure, labor cost, technical assistance, approvals etc.) and the useful surface of the building.

Operational cost C_2 represents the annual cost for the building's utilities divided by the unit of surface.

The cost of maintenance and renovation C_3 represents the ratio between the cost of the respective works and the useful area of the building.

Time of construction CP_1 is calculated as the ratio between the total number of workers multiplied by the number of hours (W) per surface unit.

$$\mathrm{CP}_1 = \frac{\mathrm{W}}{\mathrm{A}} \quad (7)$$

The production rate CP_2 calculated with the formula:

$$\mathrm{CP}_2 = \frac{\mathrm{C}_1 + \mathrm{C}_2}{\mathrm{CP}_1} \quad (8)$$

Construction schedule CP_3 is given by the smoothing factor C_a:

$$\mathrm{C}_\mathrm{a} = \frac{W}{D \times R_{\max}} \quad (9)$$

where:

D - total time for the construction of the building
R_{max} - maximum number of workers on site, at the same time

Life cycle efficiency Ef_1 represents the life cycle of the building without being necessary major renovation or rehabilitation of the structure.

Area efficiency Ef_2 is the efficient use of the space, calculated as a ratio between the useful area (A_n) and the entire built area (A).

$$Ef_2 = \frac{A_n}{A} \quad (10)$$

The social criteria

Cf_1 is estimated depending of the degree of thermal comfort throughout the year, both in summer and in winter

Noise and acoustic comfort Cf_2 is given by the airborne sound insulation $D_{n,t}$ and by the impact sound insulation $L_{n,w}$:

Airborne sound insulation:

$$D_{n,t} = R + 10\lg(\frac{A_0}{S}) \quad (11)$$

where:

R - sound reduction index
A_0 - reference area 10 sqm
S - total surface of the rooms

$$R = 10\lg(\frac{1}{T}) \quad (12)$$

where:

T - sound transmission coefficient

$$T = \frac{\rho_0 \times c}{n \times f \times m} \quad (13)$$

where:

$\rho_0 \times c$ = acoustic impedance
n - number of surface parts
f - frequency
m - mass/unit area of the partition

The average transmission coefficient for composite partitions is:

$$T_{av} \times A = \sum_{i=1}^{n} T_i \times A_i \quad (14)$$

where:

A - total area of partition

T_i - transmission coefficient for surface part i

A_i - area of surface part i.

Impact sound insulation represents the insulation for noise generated in the building by: footsteps, general repairs, moving furniture etc.

$$L_{n,w} = L_{nw,eq} - \Delta L_w \, (15)$$

$$L_{nw,eq} = 164 - 35 \times \lg m \quad (16)$$

where:

$L_{nw,eq}$ - level of sound pressure caused by footsteps on the finished floor slab

ΔL_w - level of sound pressure caused by footsteps on the floor slab without finishes.

m - the mass of the slab/unit of surface.

To determine the visual comfort Cf_3 we calculate the average daylight factor ADF using the equation:

$$ADF = \frac{M \times A_w \times \theta \times T}{A \times (1 - R^2)} \quad (17)$$

where:

A_w - total area of windows or skylights

M - correction factor

θ - angle of visible sky

T - glass transmission factor

R - area weighted average reflectance of the room' surfaces.

A - total area of room' surfaces

The quality of the indoor air is measured by three factors: the concentration of volatile organic compounds in the indoor air IAQ_1, CO concentration in the indoor air IAQ_2 and the effectiveness of ventilation in naturally or mechanically ventilated spaces IAQ_3

The safety of the construction is evaluated by establishing the degree of flood protection (S_{a1}), fire protection (S_{a2}) and earthquake protection (S_{a3}).

The accessibility and the adaptability of the building it's characterized by coefficients that take into account: the time needed to reach the public transport system (AA_1), criteria such as: parking, elevator, WC, maneuverability (AA_2), the adaptability of the structure to new opportunities such as changing the structural system (AA_3), and finally adaptability to new energy sources (AA_4).

3 Case Study

The subject of the sustainability study is an agro-tourism guesthouse which was constructed with European funds, finished at the beginning of 2020. The payment stages were made after the performance evaluation. The investment reached the amount of 245,000 EURO, out of which 73,000 EURO represents expenses for the arrangement of the exterior spaces, furnishing and equipping the interior spaces that are not included in the actual study.

Even if the consolidation solutions are not the subject of this article, [11], an important factor is represented by the reuse of 45 cubic meters of brick resulting from the demolition of the old building.

It is an efficient and modern construction in terms of equipment, where we refer to the 32-37 kW ground-water heat pump, with a water outlet temperature of 35-60 Celsius degrees, as well as the replacement of the classic system with radiators with fan coils which in addition to comfort, it also ensures the ventilation of the rooms in all 12 months of the year. The volume of the construction is 1544.98 cubic meters and the useful surface on both 2 levels is 485.93 square meters. The footprint is 297 square meters, located on a plot of 1086 square meters. The building was designed for a life cycle of 75 years (t = 75 years).

The energy performance certificate was made by the company Certific Ro, where resulted from a high energy efficient building - class A with an annual energy consumption of 54.84 kWh/m^2/year and a CO_2 equivalent emission index of 33.96 kgC0$_2$/m^2/year. The values used in the sustainability study for energy consumption are detailed in Table 1, [12], and the values of sustainability parameters obtained by the authors are shown in Table 2.

Table 1. Specific annual energy consumption

Specific annual energy consumption	Value [kWh/m^2/year]
Heating	27,62
Hot water for consumption	13,66
Conditioning	7,56
Artificial lighting	6

Table 2. Values of sustainability parameters

Parameter name	**Benchmark**		**Calculated or estimated value**	**Point score** w_i	**Weight factor** p_i **%**	$p_i * w_i$ **points**
	$w_{i\ min}$	$w_{i\ opt}$				
	20 points	**100 points**				
En$_1$ (MJ/sqm/y) Initial embodied non-renewable energy in original construction materials	180,00	60,00	71,96	92,03	2,50	2,30
En$_2$. **(**MJ/sqm/y) Non-renewable embodied energy in all facilities of building operation (HVAC)	1.100.00	450.00	197,43	100,00	6,50	6,50
En$_3$. (MJ/sqm/y) Non-renewable embodied energy in construction materials used for maintenance, renovation and replacement works	40.00	15,00	12,59	100,00	2,00	2,00
En$_4$. **(**MJ/sqm/y) Embodied non-renewable energy in building materials after end of life	35.00	10.00	12,67	91,71	1,00	0,92
En$_5$. (%) Use of renewable energy sources	0.00	25.00	57,21	100,00	2,00	2,00
G$_1$. (kg CO_{2eq}/sqm/y) Initial GHG emissions	20.00	6.00	7,14	93,49	2,00	1,87
G$_2$. (kg CO_{2eq}/sqm/y) GHG emissions from all facilities in the building operation (HVAC)	93.00	10.00	33,96	76,91	4,00	3,08
G$_3$. (kg CO_2) GHG emissions from construction materials used for maintenance. renovation and replacement	3.00	1.00	0,84	100,00	1,00	1,00
G$_4$. (kg CO_2) End of life GHG emissions	1.90	0.60	1,05	48,57	1,00	0,49
G$_5$. (%) Heat island effect of the roof	29.00	95.00	89,00	92,73	1,00	0,93
MR$_1$. (%) Re-use of existing materials, products and structural elements, if available	0.00	50.00	24,00	58,40	1,00	0,58
MR$_2$. (kg/m^3) material efficiency	2.000.00	900.00	1045,35	89,45	2,00	1,79
MR$_3$. **(**%) Use of materials with recycled content	0.00	30.00	4,43	18,85	2,00	0,38
MR$_4$. (km) Use of local resources	60.00	5.00	17,55	81,75	1,00	0,82

CS$_{1.}$ (%) Waste from construction and demolition process sent off the site	5.00	50.00	-	10,00	2,00	0,20
CS$_2$ (%) Dust produced during construction	20.00	100.00	-	70,00	1,00	0,70
CS$_{3.}$ (%) Noise produced during construction	105.00	70.00	87,32	60,41	1,00	0,60
LW$_{1.}$ Construction on contaminated land	Yes	No	No	100,00	2,00	2,00
LW$_{2.}$ (%) Ground occupancy percentage	>30	30.00	25,43	100,00	2,00	2,00
LW$_{3.}$ (l/p/d) Potable water consumption by building occupants	180.00	90.00	-	80,00	2,00	1,60
LW$_4$. (%) Use of grey and rain water	0.00	30.00	0.00	20,00	1,00	0,20
TOTAL ENVIRONMENTAL CRITERIA - e						**31,95**
C$_{1.}$ (euro/sqm) Initial cost	650.00	300.00	354,00	78,66	5,00	3,93
C$_{2.}$ (euro/sqm/y) Operational cost	40.00	5.00	4,73	100,00	5,00	5,00
C$_{3.}$ (euro/sqm/y) Maintenance and Repair Cost	25.00	5.00	7,20	91,20	3,00	2,74
CP$_{1.}$ (man x h/sqm) Total time for the construction of the building	120.00	55.00	55,58	99,29	2,50	2,48
CP$_{2.}$ (euro/h) Production rate	6.00	15.00	12,74	100,00	2,50	2,50
CP$_{3.}$ – Ca Construction Schedules	0.40	0.90	0,87	95,20	1,00	0,95
PM$_{1.}$ (no. of documents) Initial documents	3.00	10.00	10,00	100,00	2,00	2,00
PM$_{2.}$ (no. of documents) Documents of maintenance and operation	0.00	Yes	Yes	100,00	2,00	2,00
PM$_{3.}$ Monitoring of performances	0.00	Yes	Yes	100,00	2,00	2,00
Ef$_{1.}$ y Long service life	25.00	75.00	75.00	100,00	3,00	3,00
Ef$_{2.}$ (%) Area efficiency	70.00	95.00	82,00	58,40	2,00	1,17
TOTAL ECONOMICAL CRITERIA - c						**27,77**
Cf$_{1.}$ PPD, PMV Thermal Comfort	<15	<6	-	90,00	4,00	3,60
Cf$_{2.}$ Noise and acoustic Comfort	35,00	47,00	50,43	58,71	1,50	0,88
	70,00	58,00	77,30			
Cf$_{3.}$ (%)Visual Comfort	0.50	3.00	2,07	70,24	1,50	1,05
IAQ$_{1.}$ (%)VOC concentration in indoor air	0.30	0.80	0.80	100,00	1,00	1,00
IAQ$_{2.}$ CO concentration in indoor air	Yes	No	No	100,00	2,00	2,00

IAQ₃. Effectiveness of ventilation in natural or mechanical ventilated spaces	0.30	0.80	0.80	100,00	1,00	1,00
Sa₁. Protection against earthquake	RsI	RsIV	RsIV	100,00	7,00	7,00
Sa₂. - (mm) Protection against flood	1.000.00	6.000.00	6.000.00	100,00	4,00	4,00
Sa₃ – Protection against fire	5.00	1.00	1.00	100,00	3,00	3,00
AA₁. (Min) Access to public transport systems and proximity to user specific facilities	30/50.	5/10.	5/10.	100,00	1,50	1,50
AA₂. Lifetime homes	30.00	5.00	5.00	100,00	1,50	1,50
AA₃. Adaptability constraints imposed by structure	No	Yes	Yes	100,00	1,00	1,00
AA₄. Adaptability to future changes in type of energy supply	No	Yes	Yes	100,00	1,00	1,00
TOTAL SOCIAL CRITERIA - s						**28,53**

The quantification of results was made also using Bob-Dencsak model. The score obtained for each parameter was achieved by interpolating the value between the minimum and the optimum benchmark.

The sustainability index is the sum $p_i * w_i$ of all three criteria:

$$BSI = e * 0{,}4 + c * 0{,}3 + s * 0{,}3 \quad (18)$$

where: $$e = \frac{\sum p_i^e \times w_i^e}{0.4} = 79{,}875$$

$$c = \frac{\sum p_i^c \times w_i^c}{0.3} = 90{,}90$$

$$s = \frac{\sum p_i^s \times w_i^s}{0.3} = 95{,}10$$

$$BSI = 87{,}75 \Rightarrow \quad VERY\ GOOD$$

The graphical result of the parameters *e*, *c* and *s* are presented in Figure 3, where the triangle represents the sustainability index, [13].

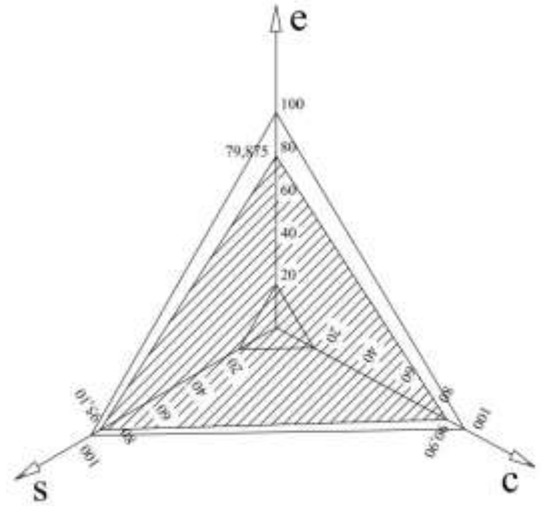

Fig. 3: The graphic result of BSI

4 Conclusion

The result of the study is a building with a very high level of sustainability, obtaining a sustainability index of 87,75.

It is observed that the environmental dimension has the lowest value, very close to a very good level. The fact that quality materials were used increased this score, but especially the reuse of the materials resulting from the demolition of the old building, as well as equipping the building with a ground-water heat pump and fan coil units. These led to low energy consumption and CO_2 emissions during the construction process, but especially during the exploitation process which seems to have the largest ratio.

A very important aspect of the economic dimension is the documentation, efficiency and follow-up of the construction, which has a ratio of 11% of the final result. If they are done responsibly a significant savings percentage is made on the cost of materials and labor. In this sense, a score of 90.90 points was achieved.

The social dimension obtained the highest score which is 95 points, being an investment in a developed area of the county, these aspects being taken into account from the beginning.

The results were obtained after analyzing a large number of factors, which allow us to identify the strong points, but also the weak points of the study.

Thus we can say that the sustainability study in the design stage could help us choose better solutions (other types of material, more efficient equipment, location) that would result in a building with a higher sustainability level.

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