Life cycle cost analysis of a pavilion school building in Portugal

Determination of annual equivalent cost and economic study of the installation of Trombe walls

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Abstract

In the construction sector, there has been increasing adherence to Life Cycle Cost (LCC) analysis because it is verified that its application leads to the optimization of the results obtained, since it is more comprehensive and considers factors that were previously ignored, but which are of enormous relevance, such as costs of the building use phase.

The present dissertation introduces a methodology, based on the one existing in European Standard EN 16627, whose purpose is to systematize the procedure to be followed to make it easier and faster to execute a LCC analysis. This methodology will then be applied to a school building, refurbished by Parque Escolar, E.P.E. between 2008 and 2009, including a life cycle of 62 years.

Also presented and analyzed in this document is a solution to improve the energy performance and thermal behavior of the building, more specifically the construction of a Trombe wall.

Keywords: Life cycle cost, Asset management, Annual equivalent value, Trombe wall

1. Introduction

Considering that in Portugal, and in many other countries, there are many buildings which are uninhabited or underexploited and in a high state of degradation, it is becoming indispensable to develop maintenance and intervention plans to increase their value, involving their rehabilitation or, when necessary, their demolition. Mainly because built assets involve large investments and therefore must be monetized in a way that allows the organizations that support them to maximize the benefits or the value obtained. One of the approaches that has been very relevant for the management of constructed assets is the consideration of the Life Cycle Cost (LCC), which considers that the analysis of the buildings should include longer periods of time and more information, making it possible to compare options and make more robust and reliable decisions, as well as anticipate long-term costs, risks and opportunities.

2. Methodology for the LCC analysis

The methodology used is based on the one presented in EN 16627 without considering risk analysis or the verification of results of previous assessments.

The objective of this methodology is to evaluate the economic performance of any type of building by considering several processes that can be adapted to the characteristics of each one and simplify the execution of future LCC analyzes. The aim is to encourage the adoption of this approach by several project and portfolio managers who wish to optimize the allocation of available resources to obtain the best possible results and, consequently, meet or exceed the needs and expectations of the various stakeholders.

This methodology consists of eleven steps, which includes various stages. These, as well as the requirements of EN 16627 to which they refer, are presented in Table 1.

Table 1 – Steps of the methodology used to analyze LCC

STEPS	MAIN STAGES	MAIN REQUIREMENTS OF EN 16627
1. Identify the purpose	• Identify the objective • Identify the intended use for the economic evaluation	6.1
2. Identify the scope	• Define the elements to analyze • Identify the life cycle stages to consider	6.1, 7.1, 7.4
3. Identify the period of analysis and the methods for the economic performance assessment	• Define the period of analysis • Define the methods for the economic performance assessment	7.3, 10, 11
4. Identify the need of additional analysis (risk and sensitivity analysis)		10
5. Identify the requirements of the asset	• Characterize the asset • Define the scenarios • Identify the limitations • Define the origin of the information	7.1, 8
6. Identify the options and the costs to consider	• Identify the options • Categorize costs	7, 9
7. Gather the costs of the period of analysis	• Identify and gather the relevant costs for each module • Estimate values • Associate each cost collected to a date • Prepare the database	7.4, 9, 10
8. Check the financial parameters and the period of analysis	• Verify the period of analysis • Verify the financial parameters	10
9. Assess economic performance	• Introduce the data • Obtain the initial results	11
10. Interpret and present the initial results	• Interpret the initial results • Present the initial results • Identify the need of new analysis	12
11. Interpret and present the final results	• Interpret the final results • Present the final results	12

3. Case Study

The methodology previously presented was applied to a pavilion school building located in Portugal which was the object of a rehabilitation made by Parque Escolar. E.P.E. between 2008 and 2009. In addition to the application of this methodology, considering the characteristics of the building, it was studied, as an alternative solution that allows the improvement of the energy and thermal performance of the school, the hypothesis of having built, during the refurbishment, a Trombe wall on the south façade of the building.

3.1. Application of the methodology

The objective of this analysis is to evaluate the economic performance of the mentioned school building to identify the most significant costs during its life cycle, to plan future costs and to compare different alternatives, among others.

Considering the object of study is in its use phase, the analysis includes the stages of its life cycle corresponding to the acquisition of the land, construction of the asset, use phase to date, including rehabilitation and, finally, a period of future use. Therefore, the period of analysis begins in 1970, when the land was acquired, and will end in 2031, 15 years after the last full year. So, the analysis period is 62 years.

To analyze the economic performance of the building, it was decided to use parameters such as Net Present Cost (NPC) and Annual Equivalent Cost (AEC), whose equations are respectively, (1) and (2):

$$\boldsymbol{NPC}\,(€) = \sum \boldsymbol{Ct} \times \boldsymbol{FD} \qquad (1)$$

$$\boldsymbol{AEC}\,(€) = \sum_{t=0}^{n} \boldsymbol{Ct} \times \boldsymbol{FD} \times \frac{d\,(1+d)^n}{(1+d)^n - 1} \qquad (2)$$

with,

$$\boldsymbol{DF}\,(\boldsymbol{n})_{past} = (1+d)^n \qquad (3)$$

$$\boldsymbol{DF}\,(\boldsymbol{n})_{future} = \frac{1}{(1+d)^n} \qquad (4)$$

$\boldsymbol{Ct}$ represents the costs of each year and $\boldsymbol{DF}$ is the discount factor. $\boldsymbol{d}$ is the real discount rate, which will be 3%, and $\boldsymbol{n}$ the number of years between the reference date, corresponding to the year of the analysis, and the date of occurrence of the cost.

The $\boldsymbol{FD}$ formula varies depending on whether it is to capitalize $(\boldsymbol{DF}\,(\boldsymbol{n})_{past})$ or to discount values $(\boldsymbol{DF}\,(\boldsymbol{n})_{future})$, which is, whether they are before or after the reference year, respectively, that is 2016, as shown on equation (3) and (4).

Regarding the characterization of the asset mentioned in step 5, it should be noted that it was built between 1975 and 1977. At the time of its construction, the asset presented a 3x3 block typology, characterized by the existence of a set of autonomous pavilions, with 3 rooms facing each of the façades, with square or rectangular plan, 3 floors and with external connection through covered galleries.

Due to the lack of periodic maintenance actions, its degradation has intensified, and it became necessary to rehabilitate the building between 2008 and 2009 with the objective of restoring its functional and structural requirements, as well as guaranteeing the comfort of its users. It was also intended to create the conditions that would meet the needs of the current teaching model.

Since after refurbishment, 39% of the school area corresponds to new construction and the remainder to rehabilitated infrastructures, since the total gross area increased from 4967 m^2 to 8107 m^2.

To capture the costs of the building, it was considered the cost modules presented in Table 2.

Table 2 – Considered cost modules

Cost Modules	
A0	Land
A1-A5	Construction
B1	Use
B2	Maintenance
B3 - B4	Repair and Replacement
B5	Refurbishment
B6	Energy
B7	Water

To estimate the values that could not be collected, it was decided that for the years before 2016, costs would vary only according to inflation from the known years. For the period after 2016, costs and methods of cost estimation were investigated for the use phase of school buildings, to find a range of values that could be used. The search for these values was done for modules B1 to B4, B6 and B7.

Once all the data were collected, it was decided that constant values would be used during the analysis, so all the values of each year were calculated with respect to the end of 2016, so the price variation over the years would no longer influence the results.

That way, the costs (C_n) of each year n at the prices of the year 2016, considering the rate of inflation (i) can be calculated as expressed in the next equation:

$$C_{n\ 2016} = C_n \times \prod_{n+1}^{2016}(1 + i_{n+1}) \qquad (5)$$

Then the values were updated, also for 2016. The updated costs, of each year (n) considering the real rate of updating (d) of 3%, can be calculated through the following equations for past and future values, respectively.

$$C_{n\ act} = C_{n\ 2016} \times (1 + d)^{2016-n} \qquad (6)$$

$$= C_{n\ 2016} \times (1 + 0.03)^{2016-n}$$

$$C_{n\ act} = C_{n\ 2016} \times \frac{1}{(1+d)^{n-2016}} \qquad (7)$$

$$= C_{n\ 2016} \times \frac{1}{(1 + 0.03)^{n-2016}}$$

After calculating these values it is already possible to calculate some financial parameters and to evaluate the economic performance of the building.

3.2. Trombe Wall

Considering that energy costs still represent a large share of the total costs of the school during its use phase, and where there is probably a greater opportunity to intervene to reduce these costs, it was decided to analyze the hypothesis of having an intervention strategy, in this case a Trombe wall, which would allow a more efficient use of energy by reducing its consumption and using less polluting and less expensive sources.

The concept of the Trombe wall was patented in 1881 by Edward S. Morse and later more developed and made known by Felix Trombe and Jacques Michel in 1957.

A Trombe wall is essentially constituted by a simple wall, an air chamber and a single or double glass on the outside. The materials of the wall must have a good thermal storage capacity and the outside should be dark to increase the absorption of incident solar radiation. Its thickness may vary according to the properties of the material, such as its density, specific heat and thermal conductivity (Martins, 2010).

This wall has the capacity to store the solar radiation that affects it, transforming it into thermal energy that is transferred to the interior of the building through mechanisms of conduction, radiation and convection.

Depending on the time lag wanted between the accumulation of heat in the Trombe wall and its transfer to the interior of the building, the wall can be non ventilated or ventilated, represented in Figure 1, which means, with openings that allow the circulation of the air between the air chamber and the interior of the building.

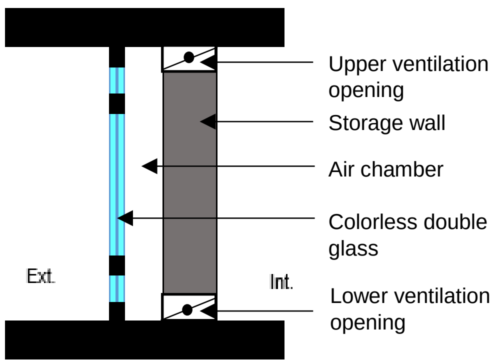

Figure 1 – Representation of a ventilated Trombe wall (Martins, 2010)

With the non-ventilated wall the solar radiation is stored during the day and the heat is transferred to the interior of the building during the night. If the wall is ventilated, it should have two ventilation openings and the thermal energy starts to be transferred by convection through them as soon as the temperature in the air chamber exceeds the temperature inside the building. This last option is most advisable if the building is used mostly during daytime, as is the case of the building of the case study, since it allows a more immediate heating of the compartments.

This system should be implemented with preferential orientation to south, with the objective of optimizing the incident solar radiation during the winter and allowing that during summer it is protected from the radiation due to the high altitude of the Sun during this season.

It is also advisable for the Trombe wall to include shading devices that can be activated at night during the winter to reduce heat losses and during summer days to avoid overheating the compartments.

To know the possible percentage of energy savings provided by the construction of the Trombe wall, several articles were investigated and with this information it was possible to create Figure 2, where a trend line represents the relationship between the percentage of floor area occupied and the percentage of savings.

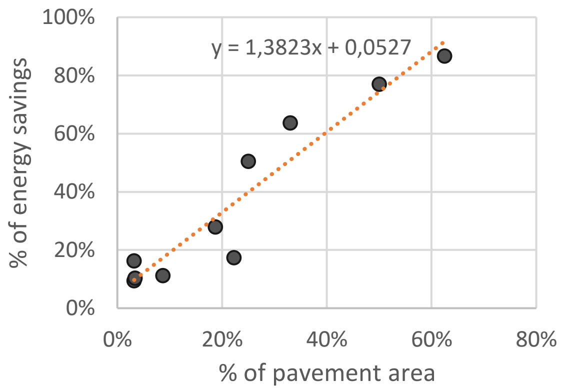

Figure 2 – Relationship between the percentage of floor area occupied and the percentage of savings

Considering the architecture of the building, it was estimated that the Trombe wall, if constructed under the windows of the three floors on the south façade, could occupy about 264 m^2, which would correspond to 6.85% of the area of pavement (8107 m^2).

Considering this value and the equation taken from the previously mentioned trend line (y= 1.3823x + 0.0527), a saving percentage of 14.73% of heating energy could be reached.

Heating energy represents only a portion of the total energy used in a building. According to the 2004 *School Operations and Maintenance: Best Practices for Controlling Energy Costs*, heating energy in a school building can reach 40%. According to Pereira (2014), heating energy in schools in the United States of America is about 47%. Therefore, it is considered that the heating energy in this school building is an average of these two values, or 43.5%. Therefore, the estimated savings, on the total energy consumed, due to the implementation of a Trombe wall is 6.41%.

The cost of its construction, compared to a common masonry wall, can increase from € 5 (Gomes, 2011) to € 91 (Real, 2010) for every m^2 of wall. Thus, it is considered that the extra cost for constructing this type of wall is the average of these values, which is, 48 €/m^2.

Considering that the wall will have an area of 264 m^2, as previously mentioned, the extra cost of its construction would be around € 12,672.

With these values calculated it is now possible to move to the discussion of the results.

4. Results and Discussion

To obtain reference values, the presented results consider discounted costs for a better translation of the reality of current costs and their variation over time. Figure 3 shows the updated costs accumulated over time.

In this that figure, the most significant increases relate to the higher costs that correspond to the acquisition of the land, construction of the asset and its subsequent rehabilitation. It should be noted that more than half of the LCC of the asset occurred until the end of its construction, which means, until the end of 1977, as can also be seen in Figure 4, where 59% of the total costs correspond only to modules A1-A5.

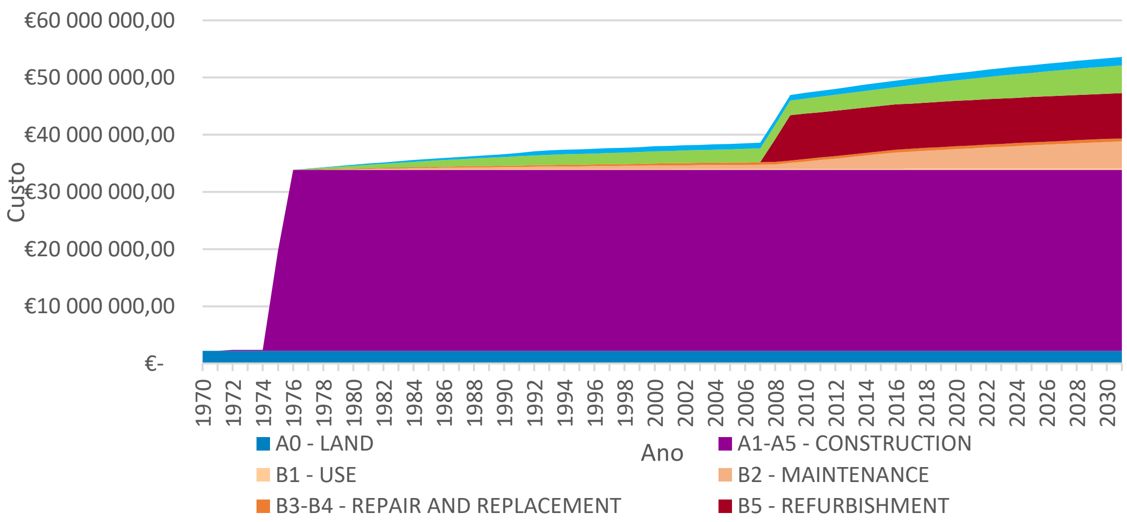

Figure 3 - accumulated discounted costs (1970-2031)

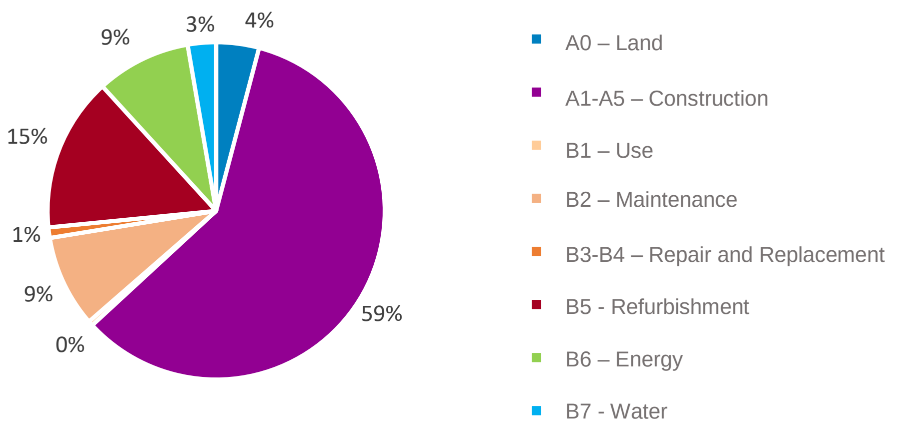

Figure 4 - Total costs distribution

This data allows to show that, in this case, the cost of construction is quite high compared to the other costs. Although the construction quality wasn't considered to be adequate, the construction cost was 31 638 307,87 €, or 6 369,70 €/m^2, well above the average value for the construction of several schools of 1300 €/m^2 referred in Almeida (2016).

Since the characteristics and dimensions of the school building changed with its refurbishment, for example, its area expanded from 4967 m^2 to 8107 m^2, and considering that one part of the analysis period occurs in the future, it was decided to divide the life cycle in three distinct phases, to be able to better analyze the results obtained. The first relates to the period prior the rehabilitation of the asset,1970 to 2007, the second includes the period from rehabilitation to the last full year, which is between 2008 and 2016 and, lastly, the period that includes the future, 2017 to 2031, where the values for the use phase were estimated.

The discounted costs for the first period, from 1970 to 2007, are presented in more detail in Figure 5.

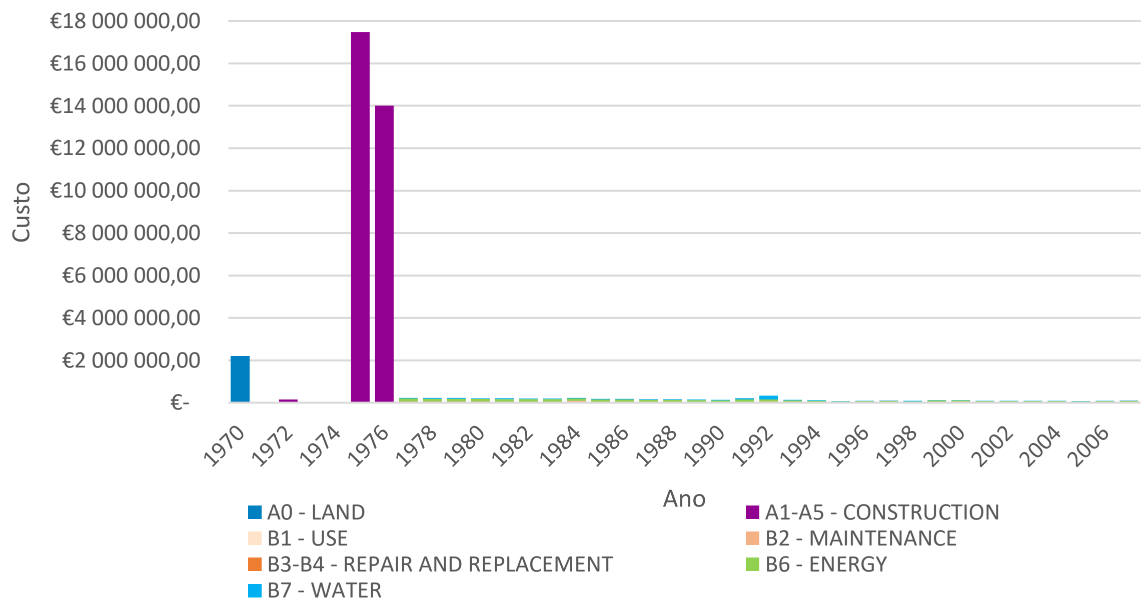

Figure 5 – Discounted costs d=3% (1970-2007)

It is possible again to verify, through the analysis of Figure 5, the disparity between the values invested in the construction of the school and those spent on its maintenance. Based on the calculations, only 0.48% of the construction cost was invested annually in the use, maintenance, repair and replacement of building elements (Modules B1 to B4). According to several authors, such as Kaiser (2009), this value should be between 2 and 4%. These values allow us to understand the progressive deterioration that the building has suffered and the need for a deep intervention to restore the standards of quality, functionality and comfort required.

As for the second period analyzed, between 2008 and 2016, it is possible to verify in Figure 6 the costs of each year, which include the remodeling of the school and the years that followed.

In this period, the approach previously followed was modified by a significant increase in the percentage of investment devoted to modules B1 to B4, which became 3.93% of the rehabilitation cost, probably to avoid the rapid degradation of the school and the decrease of its expected lifetime.

The values for the last period, for which the costs were all estimated, are presented in Figure 7.

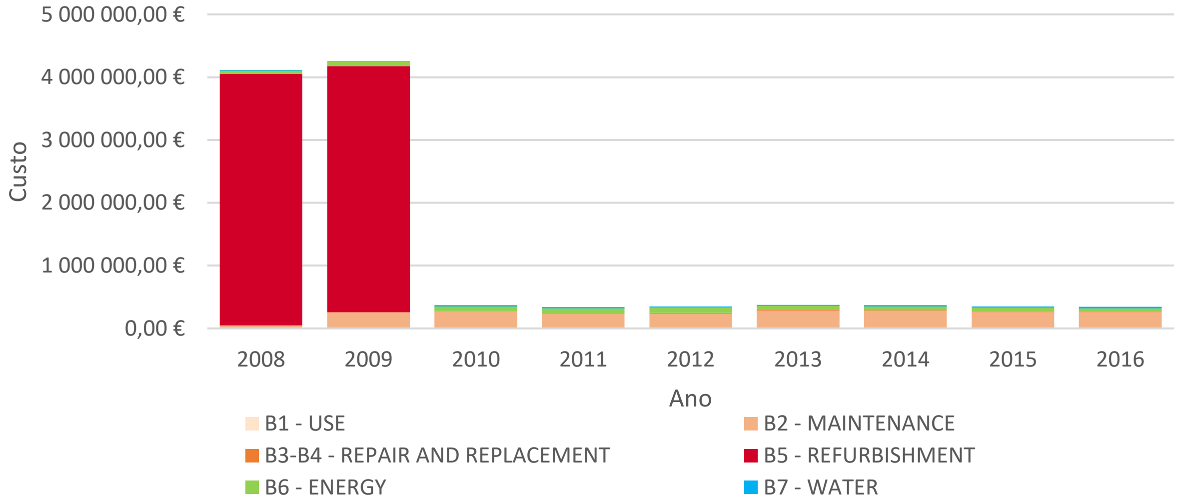

Figure 6 - Discounted costs d=3% (2008-2016)

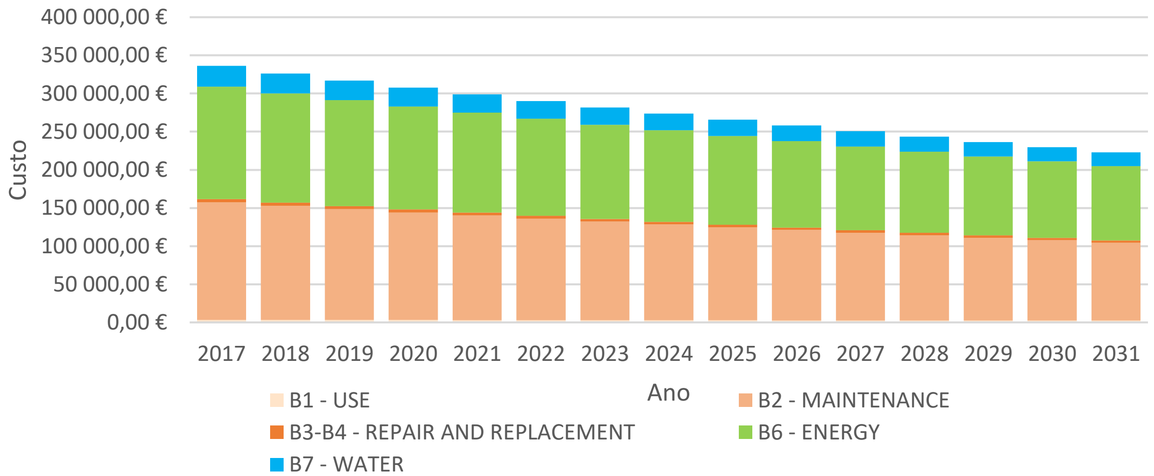

Figure 7 - Discounted costs d=3% (2017-2031)

A summary table of the values obtained for the different periods considered is presented below.

Table 3 – Discounted costs (d=3%) for the various periods considered

Períod	NPC (€)	AEC (€)	Area (m2)	AEC/m^2 (€/m^2)
1970-2031	53 594 758	1 914 075	variável	-
1970-2007	38 589 906	1 715 682	4967	345,42
2008-2016	10 866 071	1 395 571	8107	172,14
2017-2031	4 138 781	346 692	8107	42,76

By varying the discount rate were obtained the values presented in the following table.

Table 4 – NPT and AEC considering different discount rates for the total LCC (1970-2031)

Discount rate	NPC (€)	AEC (€)
1%	32 407 791	703 911
2%	41 030 261	1 160 600
3% (base value)	**53 596 827**	**1 914 149**
4%	71 862 098	3 151 462
5%	98 357 396	5 168 861

By analyzing these values it is possible to verify that an increase in the discount rate from 1% to 5% causes an increase in NPC for the triple and AEC to more than seven times greater, which demonstrates the importance that the discount rate considered has in the obtained results, being able to completely vary the decision to be taken.

It is possible, therefore, to verify that the higher the discount rate the greater the associated risk and, therefore, less appealing the investment may seem.

As for the intervention strategy, a total accumulated saving of € 139,460.17 was achieved between 2008 and 2031, which tends to increase over time, showing that the implementation of this strategy would be viable.

5. Conclusion

From the outset, it was clear the importance of an approach based on the LCC which exposes the risks of analyzing only the costs associated with the initial stages of acquisition and construction of an asset, since these, although high, represent only part of the costs, that extend over prolonged periods. The importance of operation and maintenance costs and the impact that their negligence can cause are also significant and should not be ignored.

It was also possible to understand the high importance of the discount rate, and its variation, which causes substantial changes in the values obtained and, consequently, affects the decisions that are intended to be taken from them. This, along with the period of analysis, are the parameters that greater uncertainty generate and, therefore, should be very well analyzed and controlled.

About the methodology presented, it is concluded that it is a effective way to achieve the purpose of analyzing the economic viability of any building and to assist the asset management, based on normative references.

As for the implementation of the Trombe wall, quite positive values have been obtained and, therefore, it is worthwhile to analyze its feasibility since it can lead to savings over the years and contribute to the sustainability of the building.

To conclude, the applied methodology facilitates and promotes decision making, because it allows the anticipation of opportunities and threats that may influence costs throughout the life cycle of the asset. Therefore, it promotes efficiency in projects and portfolios management throughout their life cycle, enhancing the achievement of its optimum value and allowing the growth of the organizations in which they are inserted.

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