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# 9

# LCA and LCC Analysis for the Programming of Sustainable Interventions on Building Heritage

KEYWORDS: Life Cycle Costing, Life Cycle Assessment, Suinstability, Roof, Life Cycle

The objective of the research is to deepen the importance of the use of the Life Cycle Assessment and Life Cycle Cost methodologies as decision support tools in the planning phase of interventions on the building heritage, in order to identify and plan sustainable choices for the renovation of the built. An initial theoretical treatment analyzes the concept of sustainable development starting from the analysis of the current environmental policies of the European Union; Life Cycle Thinking is a sustainable approach that allows you to move from the traditional design process to a global vision of the production system, which includes all the impacts that the product has in its life cycle.

It often happens that sustainability is reduced to the energy aspect only, leading to identifying the existing building heritage as a source of energy waste and consequently of pollution. From this point of view we often come to adopt extreme resolutions ranging from invasive redevelopment interventions, to abandonment or demolition and subsequent reconstruction. But in reality these choices, oversizing the load of the interventions, can determine a greater impact given the high waste of environmental and economic resources. On the contrary, the preservation of existing buildings can lead to less negative consequences, especially if addressed in a sustainable way.

The second part of the work consists in the use of LCA and LCC methodologies to evaluate and compare the environmental and economic profile of two different intervention strategies on a hypothetical 50 m² concrete slab roof, interested in extrados from an advanced state aging of the waterproofing coat and the intrados from mold and moisture spots caused by condensation

surface. The results of the analyzes provide several interesting indications of an environmental and economic character, useful for the conscious adoption of design choices oriented to the sustainability of the entire life cycle of the building element.

## INTRODUCTION

Growing fears about the future of the availability of raw materials and of energy supply "push" towards rapid change: the transition from a society that sees a continuous and uncontrollable growth in consumption to a model of society oriented towards sustainable consumption, in which growth economy is harmonized with environmental and social needs. This is the new challenge of the future.

A fundamental task in the implementation of a story belongs to the construction sector, that is responsible at European level of about 42% of final energy consumption, of 50% consumption of raw materials, about 35% of greenhouse gas emissions and about 50% of waste production. Impacts attributable mainly to the comparison residential (which represents about 46% of the total building stock), and in lesser measure to the non-residential sector (31%) and civil engineering (23%). In this perspective, the fundamental data are based on maintenance strategies and constructive technologies able to optimize the use of environmental resources.

The present study is aimed at reiterating the importance of the use of the Life Cycle Assessment and Life Cycle Cost methodologies as decision support tools in the planning phase of interventions on the building heritage; in order to identify and plan sustainable choices for the recovery of the built. Specifically, it describes the application of the LCA and LCC method to evaluate and compare the economic and environmental impact of two different intervention strategies that affect a horizontal opaque closure building component. The objective is to identify the less impactful construction technology through an integral "cradle to grave" analysis.

In particular, environmental assessments were conducted with the help of the SimaPro software. The intervention on a 50 m² latero-concrete roof slab, without a thermal insulation system, was suggested, interested in the extrados from an advanced state of aging of the waterproofing layer (fig.1) and the intrados from spots of mold and moisture (fig 2).

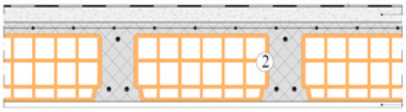
## MATERIALS AND METHODS

### Life Cycle Assessment

*Objective and scope*

To solve the problem described briefly, an external thermal coat has been provided, ie the insertion of the insulating layer in the stratigraphy of the slab, both according to the "hot roof" system and the "inverted roof" system, as well as the rebuilding of the internal plaster. An intervention on less than 25% of the gross dispersing surface was hypothesised, thus returning, according to the D.M. 26/06/2015, in the category of interventions energy requalification for which the application of the minimum requirements defined in Attachment 1 - Appendix B is mandatory. Paragraph 1.1 shows the limit values of the characteristic parameters of the building elements in the existing buildings subject to energy requalification. In order to define the climate zone, the analysis was contextualized by hypothesizing the location in the Municipality of Pomigliano D'Arco (Naples) (Climate zone C – Degrees-Day 1127). Having to guarantee a final thermal transmittance of less than or equal to 0.34 W/m²K, the two energy requalification interventions have been designed starting from the unit thermal transmittance of the existing floor, calculated through the known relation:

$$U = \frac{1}{\frac{1}{h_i} + \sum_{i=0}^{n} \frac{s_k}{\lambda_k} + \sum_{j=1}^{m} \frac{1}{C_j} + \frac{1}{h_e}}$$



It is obtained that the unit thermal transmittance of the roof slab is equal to 1,493 W/m²K. The thermo-physical parameters relating to the materials and the floor have been obtained from the UNI 10351 and 10355. At this point it was possible to choose and size the insulating layer to be inserted in the two different stratigraphy.

The project alternatives will be defined as follows:

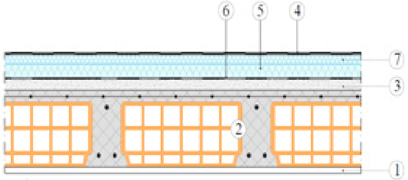
- Alternative A "Hot roof"
- Alternative B "Inverted roof"

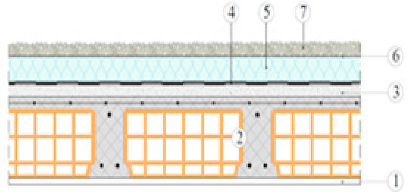
*Alternative A*

In the field of flat roofs, the type of hot roof is certainly the most widespread. As far as the stratigraphy is concerned, the alternative A (fig. 4) first involves placing on the cementitious support, by means of sludge, an armored elastoplastomeric waterproofing vapor barrier membrane (6), then an insulating layer (5) (7) and finally the waterproofing sheath also flattened near the veil glass that covers the outer insulation panel (4). The advantage of this solution lies in being known and applied for a long

Figure 1: Old demaged sheath
Figure 2: Surface affected by mold and moisture
Figure 3: Original section

time, reducing in this way the possibility of errors. Furthermore, the insulation, protected by the waterproofing layer, retains its characteristics and performance for longer and does not undergo the leaching effect. In this regard, the use of expanded polystyrene panels is foreseen extruded XPS coupled to each other for a total thickness of 8 cm, material chosen both for its high insulating capacity and because it is able to respond to higher requirements of resistance to compression and humidity. Its position under the mantle makes it necessary to use, for the outermost layer, a pre-coupled XPS panel with a bituminous membrane. The decision not to use a single panel is dictated by maintenance and economic issues that will be dealt with later. Moreover, given the absence of heavy protection, a mechanical fixing is provided, made with 5 expansion blocks per panel (one in the middle and the others in the corners, at a distance of 50 mm from the edges).





The thermophysical parameters relating to the materials and the floor have been obtained from the UNI10351 and 10355. We obtain Unit thermal transmittance U = 0,325 W/m²K ($U_{limit}$ = 0,340 W/m²K).

*Alternative B*

In contrast to the warm roof, in the inverted roof (fig. 5) the bituminous mantle (4) is laid under the insulation (5), always made of extruded polystyrene panels of 8 cm, but this time laid dry. This stratigraphy allows to protect the waterproofing layer from thermal changes, keeping it at temperatures close to those of the carrier, and also allows the elimination of the vapor barrier, whose function is directly performed by the sealing layer. To protect the insulating panels, a synthetic felt is installed and then a heavy protection in washed round gravel, which also allows access to the roof for maintenance work.

The thermophysical parameters relating to the materials and the floor have been obtained from the UNI10351 and 10355. We obtain Unit thermal transmittance U= 0,327 W/m²K ($U_{limit}$ = 0,340 W/m²K).

The definition of the boundaries of the analyzed systems consists of a necessary step to be able to construct the environmental balances of the LCA analyzes.

Therefore it was necessary to divide the life cycle phases of the two design alternatives into four groups:

- Production, which includes the off-production phases;
- Execution, which includes the phases of execution in work;
- Maintenance, which includes the phases of execution triggered by possible maintenance interventions;
- Decommissioning, which includes all the end-of-life phases.

*Inventory analysis*

The second phase of the Life Cycle Assessment forms the core of the analysis and consists in the quantitative and qualitative collection of data regarding the flows of matter and energy entering and leaving the two systems.

For this reason it was necessary to associate the materials and processes, involved in the different phases analyzed, to the data present in the databases available in SimaPro.

*Phase of production*

The following tables indicate for each material the correspondence with the databases used by the software, the source and the quantity required.

**Alternative A**

| Building material | Simapro corresponding | Source | Quantity | Unit |
|---|---|---|---|---|
| Vapor barrier | Bitumen sealing VA4, at plant/RES U | Ecoinvent system process | 100 | Kg |
| Bituminouswaterproofing membrane | Bitumen sealing V60, at plant/RES U | | 400 | |
| Polystyrene extruded XPS | Polystyrene extruded XPS, at plant/RER U | | 140 | |
| Acrylic varnish | Acrylic varnish 87,5% in H2O, at plant/RER U | | 25 | |
| Cement plaster | Base plater, at plant/CH U | | 1500 | |

**Alternative B**

| Building material | Simapro corresponding | Source | Quantity | Unit |
|---|---|---|---|---|
| Bituminous waterproofing membrane | Bitumen sealing V60, at plant/RES U | Ecoinvent system process | 400 | Kg |
| Polystyrene extruded XPS | Polystyrene extruded XPS, at plant/RER U | | 140 | |
| Gravel | Gravel, round, at mine/CH U | | 3000 | |
| Cement plaster | Base plater, at plant/CH U | | 1500 | |

Figure 4: Alternative A
Figure 5: Alternative B
Table 1: Simapro corresponding for the building materials

*Phase of execution*

To reduce the environmental impacts due to transport, the materials used for the interventions come from local factories. A choice that recalls paragraph 2.6.5 "Distance of supply of construction products" of the D.M. January 11, 2017, where it is required, for the award of the rewarding score, that at least 60% by weight of the materials used for the intervention are extracted, collected or recovered, as well as processed, within 150 km of the shipyard where they are put in place.

In the following tables, the distance of the production sites from the site and the type of transport is defined for each material (Table 2).

Furthermore, the energy consumption resulting from the use of the plaster demolition equipment and the mechanical fixing of the XPS panels for the hot roof have been estimated (screwdriver drill 3,42 kWh, demolition hammer 13,80 kWh).

As well as the consumption of water for the reconstruction of the plaster equal to 320 liters, and the consumption of propane gas for the laying of a single layer of bituminous membrane (propane gas torch 9 Kg).

*Phase of maintenance*

For the impact analysis, a useful life of 60 years was considered, for which it was possible to define the temporal cadences of the maintenance interventions envisaged for each intervention strategy. The investigations carried out to date, on existing roofs, have shown that the concept of durability of an impermeable mantle should not be separated from the system in which it is inserted, from interactions with other layers and from the presence or absence of a heavy protection able to protect it from incident solar radiation, from temperature changes, from wind and hail and other mechanical stresses. The duration of the waterproofing layer is strictly connected to the stratigraphy in which it is inserted and to the correct design of the latter.

In 1994, architect and physicist Jon-Duri Vitac completed a 16-year research on the flat roof waterproofing systems built in Switzerland. According to the author, with regard to the problem of durability, the best results were obtained with the systems where the mantle is protected, estimating for solutions such as the inverted roof a duration of 45 years. While in flat roofs covered with traditional stratigraphy and without protection, where the mantle is made of polymer bitumen membranes, the estimated duration is 25 years with poor defects. The findings published by the British Flat-Roofing Council in 1995 include the results published by the British Flat-Roofing Council in a research conducted by Napier University of Ediburg on the durability of the flat roofs. The report estimates a 20-year duration for traditional multilayer bituminous systems if reinforced with non-woven polyester fabric and a 25-year shelf life for membranes made of polymer bitumen membrane. In both cases, according to the report, there are no protection systems.

In conclusion, the life span of a bituminous mantle is 20/25 years when it is placed inside a hot roof system without protection, of 40/45 years when instead it is an inverted roof solution.

For the two alternatives analyzed, it was envisaged the use of non-self-protected bituminous membranes, ie without the protective layer, made for example with slate or grit scales. Instead they are finished with talcum or sand, so since with the solution of the hot roof they are exposed to direct solar radiations and to the consequent high temperatures of the hot months, they must be protected with acrylic paints. The duration of the protective paint efficiency has been estimated to be around 2 years. The reconstruction of the internal plaster has been foreseen every 20 years, while in the 60 years no maintenance intervention has been foreseen to the insulating layer except for the replacement of the pre-coupled XPS panel to the bituminous membrane, present in the stratigraphy of the warm roof. Operation necessary to allow the

**Alternative A**

| Building material | Type of transport | Distance | Company | Municipality |
|---|---|---|---|---|
| Vapor barrier | Transport van <3,5t/ RES U | 76,6 Km | Prebit | Battipaglia (SA) |
| Bituminous waterproofing membrane | | | | |
| Polystyrene extruded XPS | | | | |
| Acrylic varnish | | 22,4 Km | Malvin | Gricignano di Aversa (CE) |
| Cement plaster | | 14,7 Km | Cad | Caivano (NA) |

**Alternative B**

| Building material | Type of transport | Distance | Company | Municipality |
|---|---|---|---|---|
| Bituminous waterproofing membrane | Transport van <3,5t/ RES U | 76,6 Km | Prebit | Battipaglia (SA) |
| Polystyrene extruded XPS | | | | |
| Gravel | Transport, lorry 3,5-7,5t, Euro 5/RES U | 15,5 Km | Semac | Roccarainola (NA) |
| Cement plaster | Transport van <3,5t/ RES U | 14,7 Km | Cad | Caivano (NA) |

Table 2: Transport dates for the building materials

reconstruction of the bituminous mantle. It is therefore evident the economic and environmental savings obtained with the choice of using overlapping extruded polystyrene panels in the warm roof.

In summary, the following interventions were planned during the maintenance phase of Alternative A - "Hot roof":

- the reconstruction of the bituminous mantle every 20 years;
- the reconstruction of the plaster every 20 years;
- painting of the bituminous surface every 2 years.

While for the Alternative B "inverted roof":

- the reconstruction of the bituminous mantle every 40 years;
- the reconstruction of the plaster every 20 years.

The materials demolished as a result of maintenance work were considered sent to recycling or landfill, according to the following percentages:

- inert (plaster): 100% recycle;
- bituminous sheath: 100% landfill;
- XPS panel (pre-coupled to the bituminous sheath): 100% landfill.

*Decommissioning phase*

For the decommissioning phase a manual and mechanical demolition was considered, with the consequent separation of the materials and their load on the trucks.

The materials were sent to recycling or landfill, according to the following percentages:

- aggregates (plaster, gravel): 100% recycle;
- bituminous sheath: 100% landfill;
- vapor barrier: 100% landfill;
- XPS panel (alternative B): 100% recycling;
- XPS panel (alternative A): 52% recycling, 42% landfill.

In this first part, the consumption of resources and energy related to the entire life cycle of both solutions examined (input) were identified and quantified, arriving then to structure a real environmental balance with the help of the data provided by the SimaPro software database, such as emissions into air, water and soil (output).

*Evaluation of Impacts*

In this phase the extent of the environmental impacts caused by the two intervention alternatives studied was assessed. This evaluation starts from the numerical data calculated in the inventory phase and allows, through the use of aggregated indicators, for international use, to quantify the impacts and to identify the environmental criticalities. We then move from the numerical data to the judgment of danger.

With the Eco-indicator 99 evaluation method present in the SimaPro software, it was possible to quantitatively associate all consumption of resources and environmental releases to certain impact categories (formation of photochemical smog, stratospheric ozone depletion, etc.) attributable to them aimed at three major areas of general protection: Human Health, Ecosystem Quality and Resources. The results obtained from the weighing of these three categories of damage were added together (from Ecoindicator99) in a single score, called eco-indicator (Point or Millipoint), which allowed to quantify the environmental impact associated with the systems studied.

| **Building material** | **Type of transport** | **Distance** | **Company** | **Municipality** |
|---|---|---|---|---|
| Bituminous waterproofing membrane | Trasport, lorry 3,5-7,5t, Euro 5/RER U | 24,0 Km | B.Recycling | Giugliano (NA) |
| Polystyrene extruded XPS panel pre-coupled to bituminous membrane | | 12,0 Km | Eurometal | Acerra (NA) |
| Polystyrene extruded XPS | Trasport van <3,5t/ RES U | | | |
| Cement plaster | Trasport, lorry 3,5-7,5t, Euro 5/RER U | 2,8 Km | Impianti & strutture | Pomigliano d'Arco (NA) |
| Gravel | | | | |
| Vapor barrier | | 24,0 Km | B.Recycling | Giugliano (NA) |

Table 3: Transport dates for the building materials

*Categories of environmental impact*

For each phase of the life cycle of the two design alternatives, the amount of environmental damage was therefore estimated for each impact category that belongs to the materials used.

Alternative A

In the production and execution phase, the insulating panel determined the highest impact values, in particular with regard to the ozone layer reduction.

During the maintenance phase, the greatest damage was generated by the renovation of the waterproof covering and followed by the painting intervention with the protective acrylic paint.

In the decommissioning phase the impact categories have been significantly compromised by the disposal of non-recyclable materials.

Alternative B

In the phase of production and execution of the inverted roof, the greatest damage was determined by the insulating panel in extruded polystyrene foam and by the waterproofing membrane. Specifically, the insulation was responsible in particular for damage related to the ozone layer reduction and climate change, while the membrane of carcinogenic damage to humans and the use of soil and minerals.

As for the warm roof, during the maintenance phase the greatest damage is due to the rebuilding of the waterproof covering.

In the decommissioning phase all

the impact categories have been compromised by the waterproofing membrane, since it is the only non-recyclable component of the inverted roof stratigraphy.

*Categories of environmental damage*

Subsequently, the environmental impacts that compete with the two design alternatives have been traced back to the three categories of damage:

- Human Health, measured in DALY;
- Ecosystem Quality, measured in PDF * m2y;
- Resources, measured in MJsurplus.
- The results are shown as a single score (Point - Pt).

Alternative A

In the production and execution phases, the exploitation of resources represented the most significant category of damage, mainly caused by the XPS insulation panel, the waterproofing membrane and the vapor barrier.
The rebuilding and painting of the waterproofing mantle were the maintenance interventions responsible for the greater consumption of resources and the greater damage to human health and to the quality of the ecosystem. Among the causes: the need to also have to replace the pre-bitumed insulating XPS panel, the impossibility of recycling and the high frequency in having to use acrylic paint.
During the decommissioning phase, the most significant damage categories were the quality of the ecosystem and human health. Impacts determined by the fact that most of the materials used in the stratigraphy of the warm roof ends up in landfills.

Alternative B

The waterproofing membrane and the XPS insulating panel were responsible for the greatest damage in the production and execution phases. In particular, Resources was the most compromised category of damage. As for the alternative A, the rebuilding of the waterproof covering represented the maintenance intervention with the greatest environmental impact.
In the phase of decommissioning the impossibility of recycling the waterproofing membrane has determined damage to the quality of the ecosystem and to human health. On the other hand, the impacts of the remaining materials were negligible.

### Interpretation

*Phase of production*

In this last phase of the LCA analysis, a comparative assessment was made between the two design alternatives according to the environmental impacts quantified in the previous phases. In the production phase, the alternative A presented the largest environmental load in all three categories of damage, with a total impact of 123 points. The most significant gap occurred with regard to the exploitation of resources: 79.8 Pt from Alternative B against 94.5 Pt from Alternative A.
The category of impact that indicated the greatest difference between the two design solutions and at the same time the major environmental criticality of the alternative A, regarding the exploitation of resources, was that concerning the use of minerals.

| **Category of damage** | **Unit** | **Alternative A** | **Alternative B** |
|---|---|---|---|
| Human health | Pt | 22,5 | 19,9 |
| Ecosystem quality | | 6,45 | 5,34 |
| Resources | | 94,5 | 79,8 |
| **TOTAL** | | **123,45** | **105,04** |

*Phase of execution*

Also in the execution phase, the alternative A was the design solution responsible for the major damage, with a total environmental impact of 136 Pt versus 118 Pt of the alternative B.

| **Category of damage** | **Unit** | **Alternative A** | **Alternative B** |
|---|---|---|---|
| Human health | Pt | 25,7 | 23,2 |
| Ecosystem quality | | 7,67 | 6,61 |
| Resources | | 103 | 88,5 |
| **TOTAL** | | **136,37** | **118,31** |

*Phase of maintenance*

A similar speech for the maintenance phase, where the gap between the two alternatives was more pronounced not only in the category of damage related to resources but also in that relating to human health.
In this case, the total environmental impact of the hot roof solution was 43% higher than the inverted roof solution,

| **Category of damage** | **Unit** | **Alternative A** | **Alternative B** |
|---|---|---|---|
| Human health | Pt | 73,373 | 46,802 |
| Ecosystem quality | | 37,948 | 35,751 |
| Resources | | 206,729 | 139,57 |
| **TOTAL** | | **318,05** | **222,123** |

Table 4: Phase of production. Category of damage score
Table 5: Phase of execution. Category of damage score
Table 6: Phase of maintenance. Category of damage score

because alternative A needs more intensive maintenance during its life cycle. In fact, since the warm roof system guarantees a half life compared to the inverted roof, over the 60-year service life, it is necessary to carry out two restoring works on the bituminous surface, to which additionally the painting operations must be added with acrylic protective paint. two years.

*Phase of decommissioning*

Even in the decommissioning phase the alternative B was the most sustainable solution, with a total environmental impact value of 17.91 Pt compared to 24.03 Pt of the alternative A. This time, however, the categories of damage that they presented the main problems were those related to human health and the quality of the ecosystem. Damage caused by the impossibility of being able to recycle the bitumen-based material, which in the case of the stratigraphy of the hot roof system make up 86% while in the inverted roof system about 12%.

The interpretation of the results obtained considering the whole life cycle, refer to paragraph 2.3.

| Category of damage | Unit | Alternative A | Alternative B |
|---|---|---|---|
| Human health | Pt | 11,1 | 8,23 |
| Ecosystem quality | | 12,08 | 8,65 |
| Resources | | 0,86 | 1,03 |
| **TOTAL** | | **24,04** | **17,91** |

| Alternative A | | |
|---|---|---|
| | | Costs |
| **Construction** | year 0 | € 5.576,26 |
| **Maintenance** | | |
| acrylic paint | any 2 years | € 334,00 |
| remake waterproof mantle | any 20 years | € 2.267,90 |
| remake plaster | any 20 years | € 1.378,42 |
| **Decommissioning** | year 60 | € 851,73 |
| **Alternative B** | | |
| | | Costs |
| **Construction** | year 0 | € 6.977,25 |
| **Maintenance** | | |
| remake waterproof mantle | any 40 years | € 2.874,11 |
| remake plaster | any 20 years | € 1.378,42 |
| **Decommissioning** | year 60 | € 849,69 |

Table 7: Phase of decommissioning. Category of damage score
Table 8: Phases costs

## Life Cycle Costing

As for the Life Cycle Assessment methodology, also for Life Cycle Cost Analysis the phases of the life cycle of the two alternatives have been divided into different groupings:

- Construction, which includes the costs due to the phases of execution in work;
- Maintenance, which includes the costs triggered by maintenance activities;
- Decommissioning, which includes the costs due to the end of life phases.

With the help of the Price List of Campania Region and external sources, if necessary, a metric estimate 40 was drawn up for the different phases of each intervention, thus obtaining the related costs (Table 8).

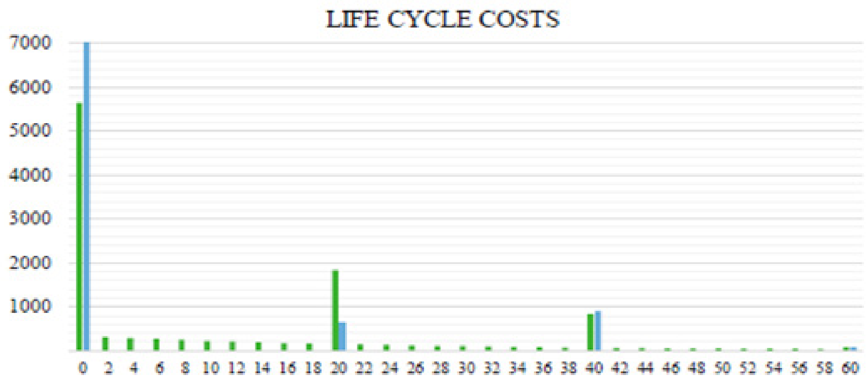
To these costs, it was necessary to add:

- costs related to energy consumption for the removal of plaster, to mix the fine mortar in the cement mixer and for the mechanical fixing of the XPS panels foreseen for the hot roof.
- the cost related to the consumption of 270 liters of water for the remaking of the plaster, 0.367 €.
- the cost related to the consumption of 130 liters of water for the construction of the subtle base screed, € 0.177;
- the cost of propane gas, used for the laying of a single layer of bituminous membrane € 27.

To estimate the Life Cycle Cost of each of the two isolation systems, it is necessary to proceed with the discounting of the tabulated costs, so as to establish the current value of a capital whose natural expiry date is a future date. It is therefore possible to identify, by applying a discount rate, a financial equivalence between the two capitals that have different maturities over time.

To "correct" the cash flows we multiply each of them by a discounting factor (actual value of the cash flow):

$$FC_t \frac{1}{(1+r)^t}$$



The graph in Figure 6 shows the trend of discounted costs throughout the useful life of the two project solutions (in green the alternative A, in blue the alternative B).

Taking also into consideration the construction cost, the sum of the discounted costs referring to the maintenance phase and the discounted cost of the decommissioning phase, we obtained the global costs.

The following table shows the discounted costs referred to each phase of the two interventions.

| | Alternative A | Alternative B |
|---|---|---|
| Construction | € 5.636,75 | € 7.037,16 |
| Maintenance | € 6.116,02 | € 1.528,55 |
| Decommissioning | € 81,19 | € 80,99 |

RESULTS

The application of the Life Cycle Assessment and Life Cycle Cost methodologies to the present study has made it possible to evaluate and compare the environmental and economic impact of the two proposed project alternatives, and therefore to identify the most sustainable solution.

The results of the Life Cycle Assessment analysis showed that alternative B represents the least impacting choice in each phase of the life cycle analyzed, obtaining in particular a reduction of environmental damage related to the use of resources and human health of around 25% compared to the alternative A (Figure 7).

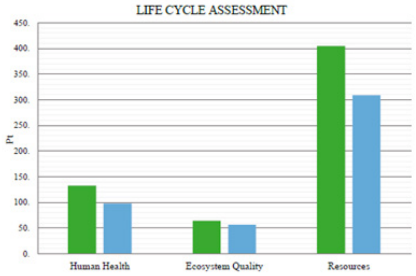
The greater environmental criticality of the alternative A, in the different categories of damage, is determined both by the need to provide for a more intensive maintenance activity and by the higher percentage of non-recyclable materials.

In this regard, considering only the waste produced by the stratigraphy of the two roofs, it is clear that the inverted roof system represents the closest solution to the European purposes regarding the recycling of construction and demolition waste (Figure 8).

The greater sustainability of the B alternative was also confirmed from the economic point of view thanks to the Life Cycle Cost analysis.

In fact, despite the higher initial cost, this alternative constitutes the most economically advantageous solution with a discounted global cost of 8646.70 euros compared to the 11833.96 euros of the alternative A.

The increase in the expenses foreseen for the hot roof was due to the maintenance phase, obtaining a difference in the maintenance costs, between the two design solutions, of 75% (Figure 9).



Furthermore, with reference to the average prices identified for the CER41 codes (European Waste Code), the costs of treatment (disposal and recycling) of waste were estimated for both design solutions, obtaining:

- ALTERNATIVE A - Total cost = € 318
- ALTERNATIVE B - Total cost = € 287

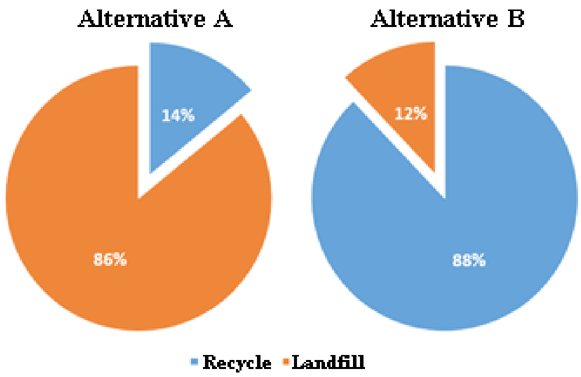
DISCUSSIONS AND CONCLUSIONS

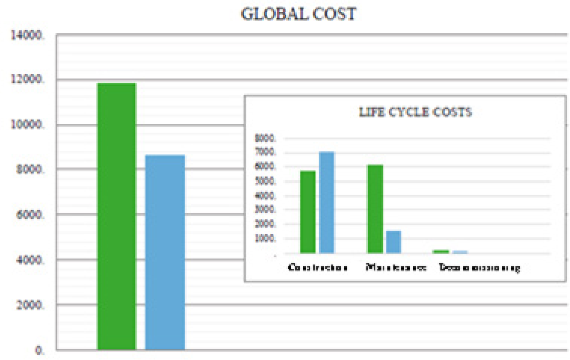
Very often the comparison in terms of economic convenience between different design solutions is carried out erroneously on the basis of the cost of realization alone.

On the other hand, forgetting that in the

| Category of damage | Unit | Alternative A | Alternative B |
|---|---|---|---|
| Human health | Pt | 132,7 | 98,08 |
| Ecosystem quality | | 64,15 | 56,53 |
| Resources | | 409,9 | 308,96 |

Figure 6: Life Cycle Costs
Table 9: Phases costs
Figure 7: Life Cycle Assessment (in green the alternative A, in blue the alternative B)
Table 10: Category of damage score





life of a building component is the rate of maintenance costs generally having a higher weight.

So the identification of the most economically advantageous solution can not ignore the use of a Life Cycle approach that allows you to have an overall economic vision, "from the cradle to the grave".

This need is clarified by the results of the LCC analysis carried out, since they show how wrong the usual belief of the constructors of considering the layer of protection in gravel an unnecessary economic burden. The latter, in fact, guaranteeing a long duration of the waterproof layer of the alternative B, allows to limit the maintenance costs to the point of reversing the result of economic convenience identified initially in the construction phase.

Added to this is the need to make the designer responsible also from an environmental point of view, so that he / she is aware that a certain design choice involves implications in terms of the impact on the environment associated with its phase of realization, use and disposal. the final. For this reason, the parameter "environmental impact" determined with the LCA analysis was included in the comparative evaluation conducted, with which it was possible to confirm once again the sustainability of the alternative B. In fact, thanks to its dry stratification, which guarantees greater reusability of the components, and the duration of its bituminous mantle, it is possible to meet the expectations of reduction of the environmental impact of the life cycle of the building intervention.

Moreover, the decision to intervene on the building envelope with a thermal coat and therefore with an energy redevelopment intervention, involves a further reduction of the impact on the environment, since decreasing the energy requirement necessary for heating decreases the amount of CO2 that is emitted into the atmosphere.

In conclusion, it can be said that "planning maintenance" with the help of decision support tools, such as the LCC and LCA methodologies, is equivalent to "planning sustainability". The maintenance therefore exceeds the definition of "maintenance of the efficiency of the services offered" to extend to a much broader science based on the reduction of resource consumption and the accountability of behaviors.

Figure 8: Recycle and Landfill percentage
Figure 9: Global costs

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