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Limitation of the environmental impacts of a heritage hotel building by Life Cycle Analysis (LCA)

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Abstract. Today, it seems that talking about the existing traditional buildings is a somewhat elegiac vision in the face of the magnitude of the global changes that are currently taking place, yet it is a truism to repeat that without this, the city would lose its anchorage and its identity; as a result, and so that it can move at the same rhythm of the changes that are continually reshaping its physiology, it seems urgent today to reconcile energy performance with the architectural qualities of its built environment. The present work aims at reducing the pressure on the environment by intervening on a heritage hotel building located in Central Algiers through a comparative LCA with a low consumption hotel building in France, in order to reduce its generation of environmental impacts, particularly carbon dioxide, while identifying the contribution of the main sources to the overall balance and thus know which elements of this building require special attention in the effort to reduce the impacts generated for a possible renovation. This objective was achieved by a double evaluation, one energetic and the other environmental by LCA which enabled us to develop a new variant emitting 60% less CO₂ while preserving the heritage qualities of our building.

Keywords – Heritage hotel; LCA; Environmental impact, Impact sources; Carbon dioxide.

1. Introduction

Hotel construction is considered to be one of the largest emitters of greenhouse gases; in 2005 it emitted 274 million tons of CO₂ worldwide, i.e. 21% of the total quantity emitted by the world tourism sector[1]. Moreover, according to a new report published by the Global Alliance for Buildings and Construction on December 7, 2018, the building and construction sector has a huge untapped potential to reduce Greenhouse Gas (GHG) emissions [2] through energy efficiency aimed at better environmental preservation. In this context, we can find, in the literature, different studies on building behavior aiming at a better environmental optimization; this context has interested several researchers [3–7], some of whom have used the Life Cycle Assessment (LCA) method to evaluate the environmental performance of buildings [8–16]; Which have made it possible to control the correlation between the constructive characteristics of buildings, their energy consumption and their environmental performance. This very fertile research context still attracts the interest of researchers given the typological diversity of buildings and their behaviour with regard to the environment. This is why, through this work, we are trying to better enrich this context and contribute to a better integration of heritage buildings in more sustainable framework, through the identification of the impacts generated by a heritage building such as a hotel and the contribution of its various sources of impact to the overall balance sheet in order to know where it should act, in order to limit its impacts for a better environmental optimization while preserving its heritage character.

2. Methodology

2.1. Methodological approach

Several methods exist for the evaluation of environmental impacts at the building level, which differ according to their evaluation approach, from the latter, we can cite: Checklists, which are very effective in the preliminary selection phase; labeling methods, which enable a label to be developed and used as a reference; matrices, which perfectly consider the interactions between project activities; decision-support methods, which enable the best alternative to be chosen by comparing different options; and finally LCAs, which are not only effective in assessing environmental impacts but are also considered to be decision-support methods [17]. In this context, the methodological approach we have chosen is based essentially on LCA, which will allow us to assess environmental impacts and compare the behavior of two alternatives. It is considered, moreover, as the only method that can avoid the transfer of pollution from one stage to another of the life cycle, or from one impact to another and from territories, as a result of a comparative study carried out between different methods based on the study of flows and energy [18]. The phases concerned are summarized in the figure 1.

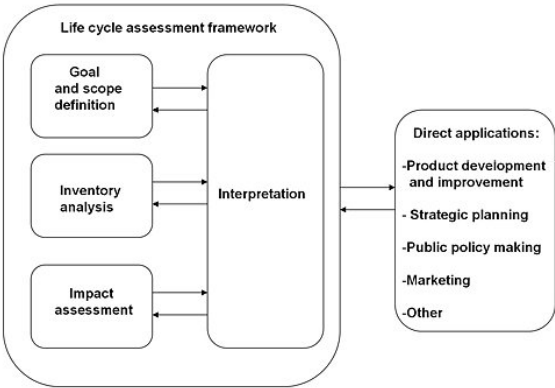


Figure. 1 : The LCA phases [19]

In addition, the impacts to be assessed in this work are illustrated in the following figure, which summarizes the life cycle through the quantification of inflows and outflows and their translation into environmental impacts ‘figure 2’.

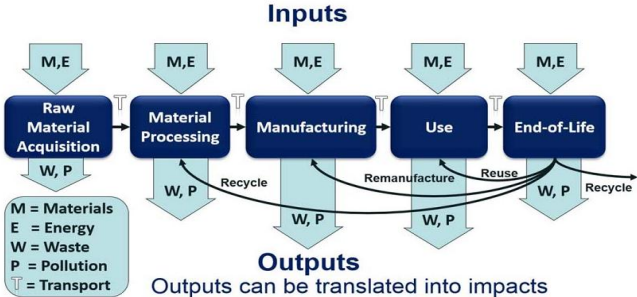


Figure 2: Inputs and output over the life cycle of a building [20]

2.2. Simulation Approach

Our simulation approach is based on a software chaining integrated in Pleiades software [21] . We started this approach by modeling our case study via ALCYONE, then we carried out a dynamic thermal simulation using the COMFIE software, the results obtained are then transmitted to EQUER in order to be able to carry out an evaluation of the environmental impacts via an LCA. In the context of our work, this approach will consider the whole life cycle of our building in order to know where to intervene for a better reduction of environmental impacts during its renovation.

3. Case studies

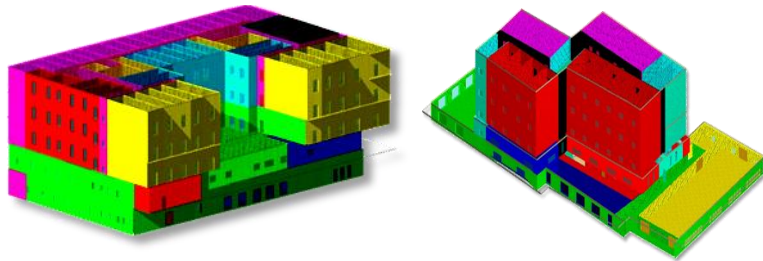
The heritage hotel building selected for an environmental optimization through the identification of the sources of impacts and their contribution to the overall balance, is a hotel building, named “Es-safir”, located in central Algiers on the seafront, it was erected in 1930, it has 150 rooms ‘figure 3 (a)’. The modelling of this case study is illustrated in figure 4 (a). In order to limit the impacts generated by our case study, we compared it to a low- consumption hotel building located in the technology park in Saint-Priest (Lyon-France), named "Golden tulips", it has 123 rooms and was completed in 2009 ‘figure 3(b)’. The modelling of this case study is illustrated in figure 4 (b).



(a)

(b)

Figure 3: case studies: Es-safir (a) and Golden tulips (b)



(a)

(b)

Figure 4: case study modelling by ALCYONE-PLEIADES software

Their general characteristics as well as the retained scenarios are presented in Table 1.

Table 1. General characteristics of the variants compared and scenarios selected

Variants	Heritage Hotel Building	Low- Consumption Building (LCB)
Location	Central Algiers (Algeria)	Saint Priest -Lyon(France)
Date of construction	1930	2009
Envelope	Traditional	Low consumption
Main materials used	Stone	Concrete
Climate	Mediterranean	Semi-continental
Number of simulated levels	5	5
Heating and air conditioning	Heating and cooling have not been activated in order to know their impact on the energy and environmental behavior of buildings.	
Ventilation	Natural ventilation	Double flow VMC with heat exchanger (0.6 vol/h)
Energy	Natural gas (100%)	Natural gas (heating) and wood energy (Domestic Hot Water)
Water	300l/d/p	250l/d/p
Waste	1500g/d/p	1000g/d/p
Simulation time	80 years for the both case studies	

The technical characteristics of our two buildings are summarized in the following table 2

Table 2: Technical characteristics of the case studies

		Heritage Hotel Building	Low- Consumption Building-(LCB)
External wall		Stone wall (60cm)	Generic insulator (20cm) Heavy concrete (16cm)
Interior wall		Stone wall. (30cm)	Cinder block (20cm)
Low floor	Components	Floor on arches (17.5cm)	generic insulation (15cm)+ Heavy concrete (20cm)
	Thermal bridge	1w/mK	0.25w/mK
Intermediate floor	Components	Antique mortar floor (light wood 2.5cm+ mortar 3cm +tile.2cm)	Heavy concrete (20cm)
	Thermal bridge	1w/mK	0.35w/mK
High floor	Components	plaster ceiling with lathing between centers (17.5cm)	Wool of glass (26cm) +. Gypsum plaster (1cm)
	Thermal bridges	0.71w/mK	0.29w/mK
Carpentry	Window and French door/ heat transfer coefficient (U)	Single glazing Uframe=3 W/ (m ² . K) Percentage of light=63%.	Double glazing low emissivity Uframe = 2.1 W/ (m ² . K) Percentage of clear = 85 Uv glazing vertical = 1.3 W/(m ² k)
	Door /heat transfer coefficient (U)	Wooden door, Uframe=5 W/(m ² .K)	Insulating door Uframe = 1 W/(m ² .K)

4. Results

In order to be able to identify the sources of impacts and their contribution to the overall balance sheet, it is important to go through a double simulation, the first will concern the energy component and the second the environmental one. The results of the first simulation are illustrated in the figure 5 which shows us the heating needs of the Es-safir heritage building compared to the LCB. In the same simulation, and in order to obtain relevant and conclusive results, we have affected the same scenarios, climate, surface and shape to our building, by assigning those from LCB to our heritage building. Thus we have five variants: the LCB; the basic variant represented by our heritage building; a variant with the shape and surface of our heritage building but with LCB materials; a variant identical to our heritage building but to which we have attributed the low consumption scenarios of LCB and a last variant identical to our heritage building but in a semi-continental climate. The cooling requirements have also been carried out, but we will only present the results of the heating requirements, given their importance.

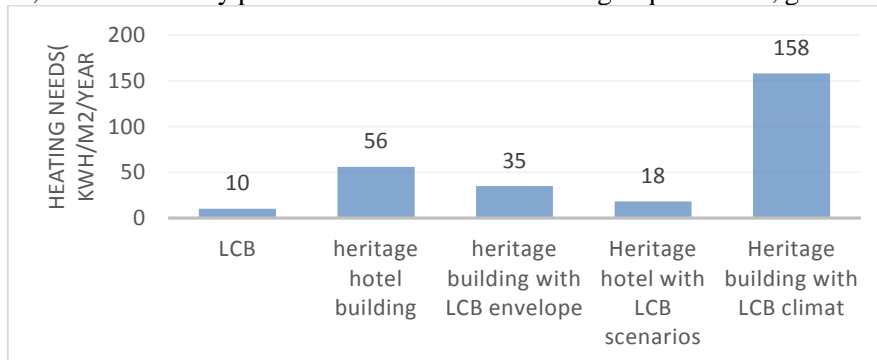


Figure 5: Heating requirements comparison between heritage building and LCB before and after assignment of the same scenarios, climate and shape

The second evaluation is environmental, we have evaluated a comparative LCA between our two buildings in impact value by considering the same surface area, the same number of occupants and the same climate. The results obtained are illustrated in the following figure 6.

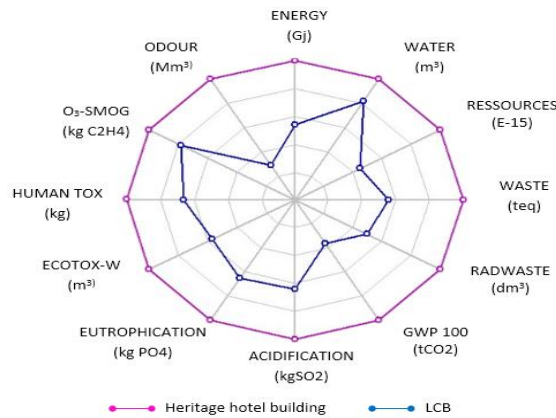


Figure 6: Comparative LCA between the Es-Safir heritage building and LCB during their life cycle by impact value

We subsequently identified the sources of impact generated by our heritage building 'figure 7'.

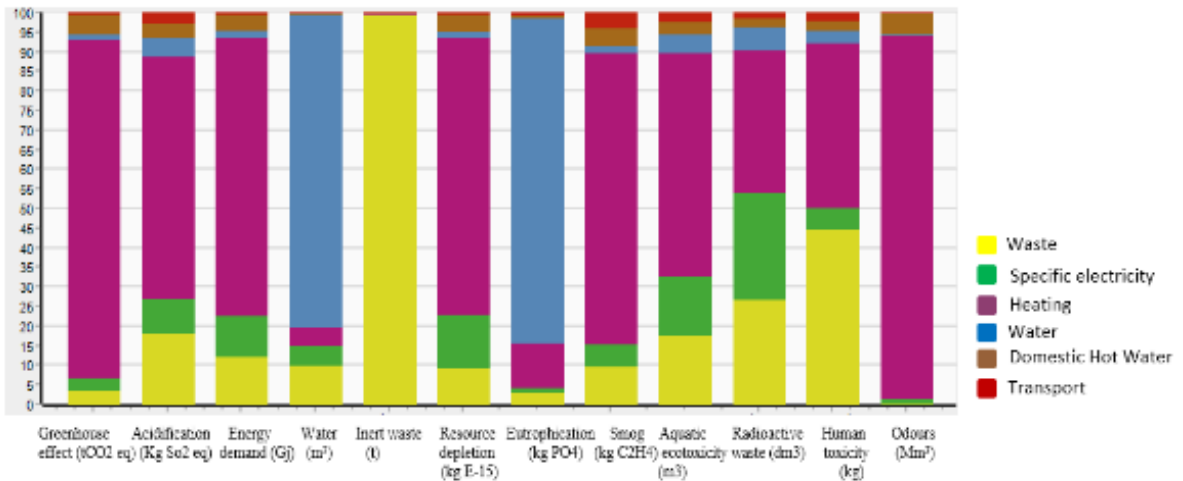


Figure 7: identification of the sources of impact of the heritage building throughout its life cycle

In order to reduce greenhouse gases, in particular carbon dioxide, we have identified the sources of this impact by life phase of our heritage building, in order to know which elements should be treated for a better limitation of this impact, as well as the contribution of each phase to the overall balance sheet 'figure 8'.

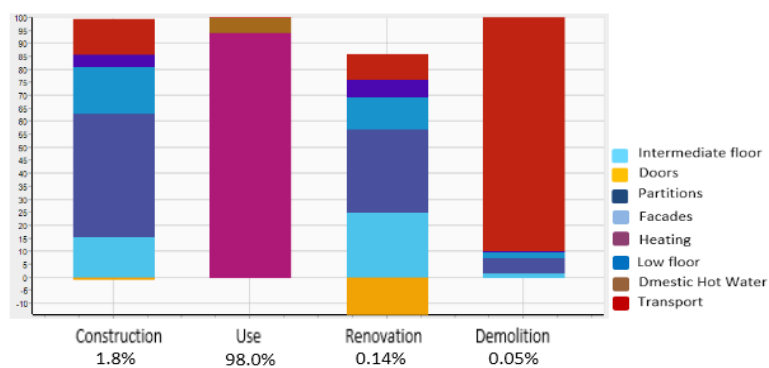


Figure 8: Identification of greenhouse gas impact sources by life phase

5. Discussion

The results obtained by the first simulation show the high consumption of our building, whose consumption is 5 times higher than that of the LCB. We also note that the gap has decreased by affecting the same surface, shape and especially scenarios of the LCB building, however, by affecting its climate, the heating needs have greatly increased, which confirms that the construction techniques of the heritage building are more compatible with the Mediterranean climate than the semi-continental one.

The results of the environmental simulation by LCA, show that the Es-Safir heritage building is more generating environmental impacts than the LCB. On the other hand, the identification of sources reveals their variation according to their nature, where we note that the predominant source for almost all of the impacts is that of heating, with the exception of the impact of waste and that of water use, whose main source is respectively the production of waste and the unbridled consumption of water.

In addition, we note that the sources responsible for generating the impact of the greenhouse effect differ from one phase to another, in fact, during the construction phase, the construction of partitions (45%) is the main source of this impact, including the extraction and manufacture of materials, followed by construction of facades (18%), intermediate floors (15%) and the transport of materials (15%), However, during the use phase, heating explains the greatest contribution to the generation of the greenhouse effect (85%), we also note that the renovation phase presents almost the same sources as those identified during the construction phase with different contributions, mainly ; partitions (30%) and the intermediate floor (21%). Finally, for the demolition phase it is the transport of materials that is responsible for the greenhouse effect with (90%) contribution.

So we can say that carbon dioxide, of which the importance depends on the most dominant height in the bars of the different phases, is generated by materials construction during the construction phase, the transport of materials, during the two phases of construction and demolition, and mainly by heating during the use phase. Its reduction is therefore correlated to the heating mode chosen and to the distance between the site of materials extraction and the project worksite.

6. Environmental optimization

Based on the results obtained, and with the aim of improving the results of the LCA, we tried to develop a variant that generated fewer impacts than the previously simulated case study. We named this new variant (LIB) (Low Impact Building). The LIB is a low impact building with the same heritage building envelope while maintaining its surface area and shape. the LIB represents an energetic renovation of our building aiming at reducing its environmental impact, especially its CO₂ emissions, this renovation is based on a sobriety and energy efficiency while carrying out a good management of energy, water and waste. In order to ensure these properties to the LIB, we have retained the following environmental assumptions:

- Natural gas for heating, wood energy for DHW (Domestic Hot Water);
- Hot water consumption: 40l/p/d, Cold water consumption: 200l/p/d;
- Selective collection of glass: 50%, Selective collection of paper 30%;
- Incinerated waste: 30% with 80% recovery by natural gas incineration: 1000g/p/d of waste produced;
- Distance between the material extraction site and the construction site: 20km

For the energy balance, we assigned the LIB the LCB scenarios, as it is characterized by low consumption. We then carried out a comparative LCA between our heritage hotel building and the LIB we propose, the results of this simulation are illustrated in the figure 9;

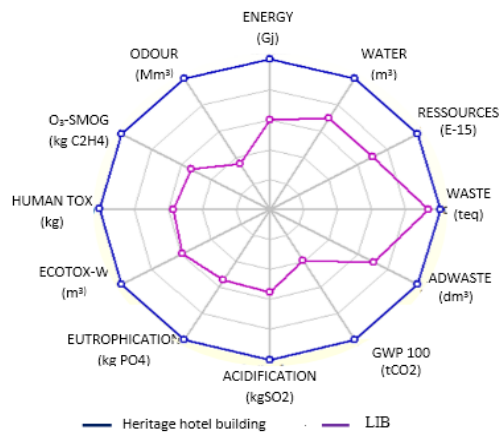


Figure 9: Comparative LCA between heritage hotel building and LIB

The results of the EQUER software, show a remarkable reduction of all environmental impacts for our heritage variant; and above all the impact of the greenhouse effect through a very considerable reduction in carbon dioxide emissions. Indeed, considering the twelve impacts, the Es-Safir heritage building is: 60% less CO₂ emissions; 41% less energy consuming; 29% less producer of radioactive waste; 30% less water consuming; 30% less consuming of exhaustible abiotic resources; 6% less producers of inert waste; 45% less generators of substances that cause acid rain; 45% less generators of substances leading to excessive eutrophication; 41% less emitting substances toxic to fauna and flora in the aquatic environment; 43% less emitting toxic substances; 47% less emitting substances that cause summer smog; 65% less emitting substances that generate odours.

Close or similar reductions could also be achieved if we opt for solutions that best exploit the environmental specificities of Algiers, particularly the climate, thus, the use of solar panels for the DHW would allow a reduction in emissions induced by a potential long distance between the materials extraction site and the construction site. Finally, we can say that thanks to the technical and energy performance of the LIB, our heritage building is less impact-generating. So, to preserve our environment, we must think about changing our behaviour as users of buildings by being more responsible with regard to what we consume as water and energy, and what we produce as waste.

7. Conclusion

The built heritage, and more specifically hotels, is considered to be one of the most energy-consuming sectors, one of the greatest users of natural resources and one of the biggest polluters. It explains a significant part of the increased environmental degradation that it is urgent to limit. The present work aims to offer not a utopian panacea for the damage observed and the resources engulfed over the last 60 years, but a means that can alleviate the intensity of this environmental decay by intervening on a heritage hotel building by striving to reconcile its environmental performance with its heritage qualities. In order to achieve this goal, we carried out an environmental optimization represented through the LIB variant that we proposed. The latter has led to a very significant reduction in environmental impacts of our existing heritage hotel building, in particular CO₂ emissions, which have been reduced by 60% through the use of low-energy consumption eco-techniques, while reducing the consumption of cold water, DHW and the production of waste by selecting and recovering it, and reducing the distance for transporting materials.

For a new building, in a Mediterranean climate, it is necessary to think about introducing low-energy eco-techniques that offer a very satisfactory environmental balance: 1. good thermal inertia of the materials; 2. generic insulation of the vertical and horizontal walls; 3. reduction of thermal bridges by external insulation; 4. Low-emission double or triple glazing. The consideration of these solutions would allow for better environmental preservation

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