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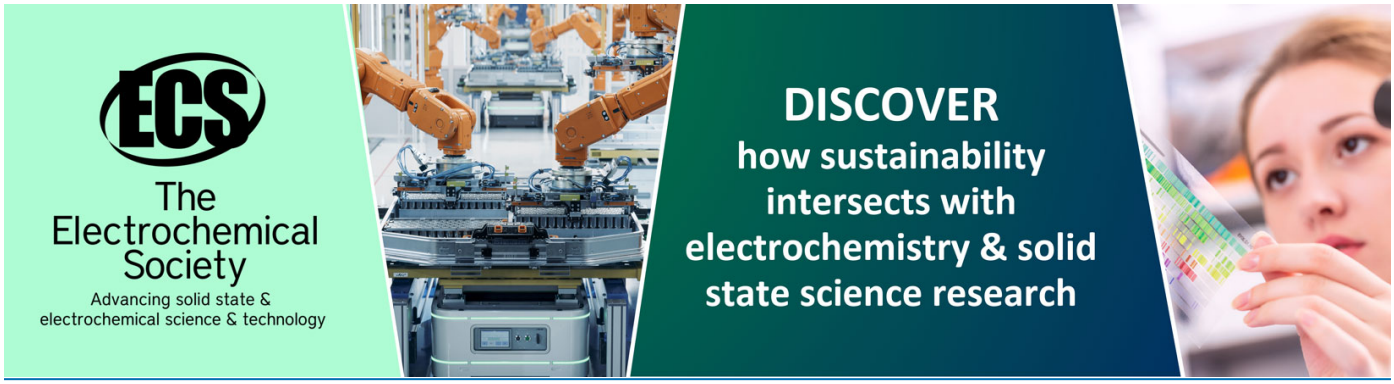

Life Cycle Assessment (LCA) in the construction of healthcare buildings. Analysis of environmental impact.

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Abstract. Currently the optimization of raw materials, energetic efficiency and the reduction of environmental impact are aspects of such importance at the time of choosing a product, process or system. The healthcare buildings are a kind of building composed by a whole group of systems, products and processes. This means a great margin for improvement in energy efficiency and environmental impact caused during the construction as well. The main goal of this project is to verify the viability of applying a case of study of Life Cycle Analysis (LCA) in a healthcare building. After the analysis of the results obtained in previous studies, a series of advantages and drawbacks have appeared as a result of applying this tool in healthcare buildings. The result has been beyond satisfactory, since clear conclusions have been obtained from an exhaustive analysis. Among the most important conclusions, it should be noted that the LCA technique is a great asset to evaluate environmental impacts. The application of LCA methodology helps to reduce the total environmental impact generated during the construction of a healthcare building, having a great impact on social benefit as well as an economic benefit. This last is usually associated to the reduction of waste and operative costs and in the energy savings. Also, it has been proposed some solutions to the main drawbacks. These can be the draw of a guide for the application of the LCA technique or the implementation of educational courses.

1. Introduction

The aim of the study is to evaluate the environmental impact linked to a product, process or activity is called Life Cycle Assessment (LCA). For the implementation, it has to been taken into account the whole life cycle, process or activity. This means, it has to be outlined the computation of all the energy and system resources, identifying their inputs and outputs along the other environmental impacts it may generate.

In a wide sense, three different of LCA focuses exist: the one based on processes, the economic input-output (EIO) and hybrids [1]. The analysis based on processes is an ascendent method of common use that implies the identification of all the resources and energy fluxes associated to different activities involved in the production and to quantify the correspondent environmental impacts [2]. The method represents the majority of studies in building technology fields due to their precision and detailed process [1]. The LCA based on processes is highly recommended for the standards of the International Organization for Standardization (ISO) due to its precision and detailed process [3]. According to ISO 14040 and ISO 14041, the investigation of LCA is divided in four steps [4,5]: the definition of a goal and approach [5], analysis of inventory (recompilation of inputs and creation of inventory) [6] evaluation of environmental impact [1] and interpretation (quantification and evaluation of the results) [7].

The aim of applying LCA to constructions and reforms of buildings is to choose the measures [8] for the modernization of buildings with low cycle environmental impact [9,10].Some studies have integrated LCC (life cycle cost) [11,12], LCA and social LCA, doing sustainable evaluations of the life cycle [13]. Also, with the purpose of looking for strategies for reducing the global warming effect [14,15], some academics have evaluated the CO_2 emission in buildings [16]. From this purpose of implementing LCA in buildings, the need of incorporate this kind of studies in hospitals is born. The different constructive elements that a healthcare building host take a double task: the first one would be to generate a gap among rooms and second one would correspond to a correct isolation of the different rooms that they are made of. Therefore, the selection of building materials becomes a so important task in which takes special relevance the philosophy of environmental impact and sustainability because, in general, these materials make a great environmental impact.

The main goal of this study is to evaluate the advantages and drawbacks of implementing the LCA in healthcare buildings. This way, it is pretended to demonstrate the importance that this methodology in the reduction of environmental impact generated along the whole life period in a sanitary building. This favors other factors such as: reduction of waste, reduction of raw materials extraction, economic saving, energy efficiency, etc.

2. Methodology

A commission of study for the Life Cycle Analysis in a healthcare building consists on analysing each one of the elements, processes, systems, installations, etc… that compose them. The total environmental impact generated in the construction of the building has been obtained in this way. There are several methodologies to get this. The most used currently are ReCiPe and Eco-Indicator 99. Now, a brief summary is showed carried out by the ReCiPe methodology in order to have a better comprehension of the LCA method.

ReCiPe has midpoint impact categories (oriented to problems) and end point categories (oriented to damages). The characterization coefficient of midpoint is multiplied by damage coefficients, in order to obtain the characterization values of the endpoint. In the midpoint 18 categories are being discussed, whereas in the endpoint categories, the majority of this midpoint impact categories are multiplied by damage coefficients and three endpoint categories are added. The three endpoint categories are normalized, weighted and added in a single mark. Figure 1 shows the relations between the life cycle inventory parameters (LCI) (left side), the 18 midpoint categories (middle) and the three endpoint, single mark included (right side).

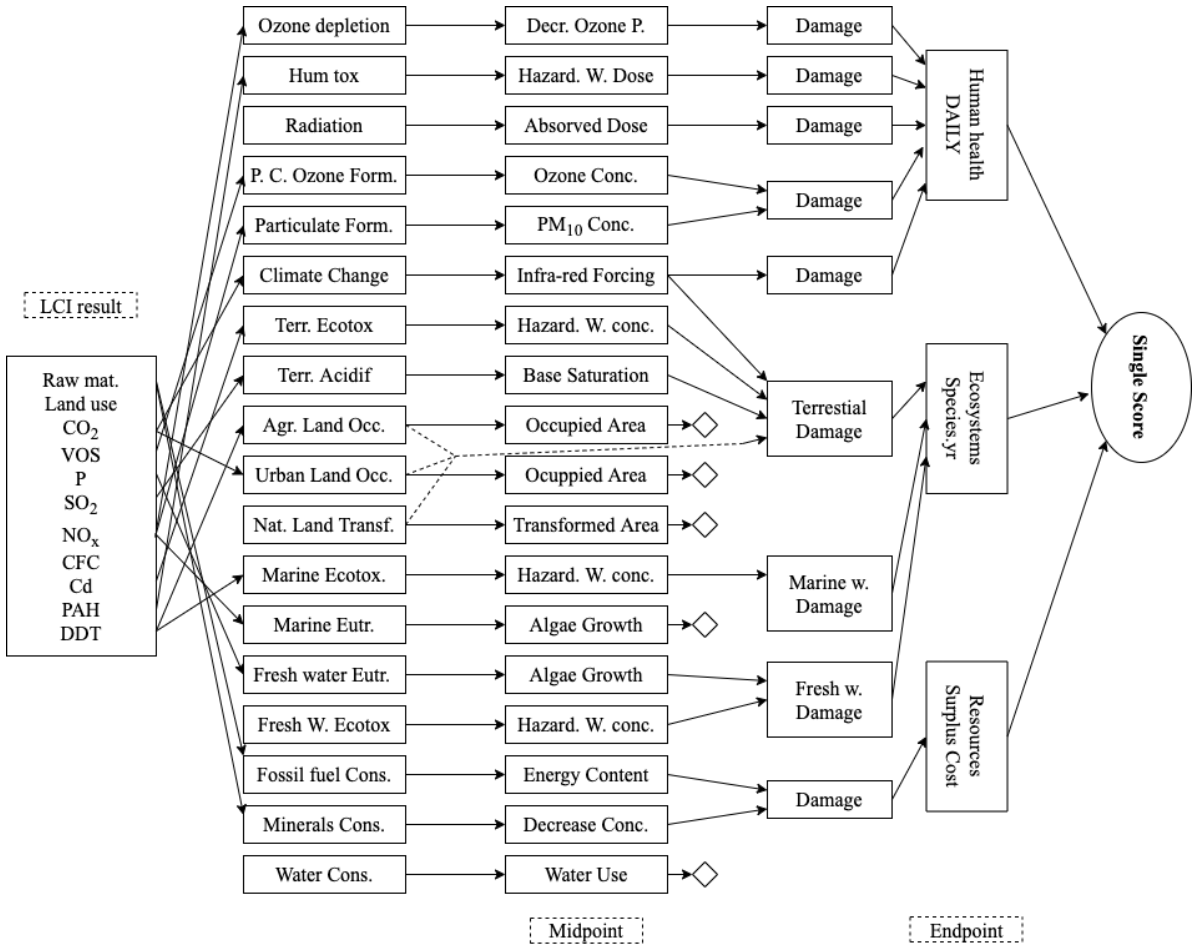

Figure 1. ReCiPe methodology. Source: Adapted from [17]**.**

Once the brief summary about the LCA methodology in healthcare buildings has been drafted, a comprehensive bibliography research has been carried out in different webs and scientific papers.

In the first place, an exhaustive search of related studies was performed in studies related to both the healthcare and the construction field. Once the bibliography was found, two actions were carried out in parallel. On one side, with the sanitary bibliography a study was conducted to know the art state. The focus was to check the viability of the project. On the other side, the building bibliography was analysed with the objective of obtaining the different characteristics that the LCA methodology provides when it is applied in the building field.

When the different characteristics from each bibliography were obtained, it was the turn for a results analysis. From which a series of advantages and disadvantages of the application of this tool to sanitary buildings were extracted. To do this, each study had to be thoroughly examined, in order to extract the most appropriate information for this type of building. This process was repeated several times in order to convey the most objective information possible. For the time this advantages and disadvantages were obtained, it was pursued to evaluate later the viability of the application with the LCA methodology for healthcare buildings, so the different synergies born from this relationship could be visualized.

As a summary, a graphic scheme is presented of the methodology carried out in this project. This is showed through Figure 2.

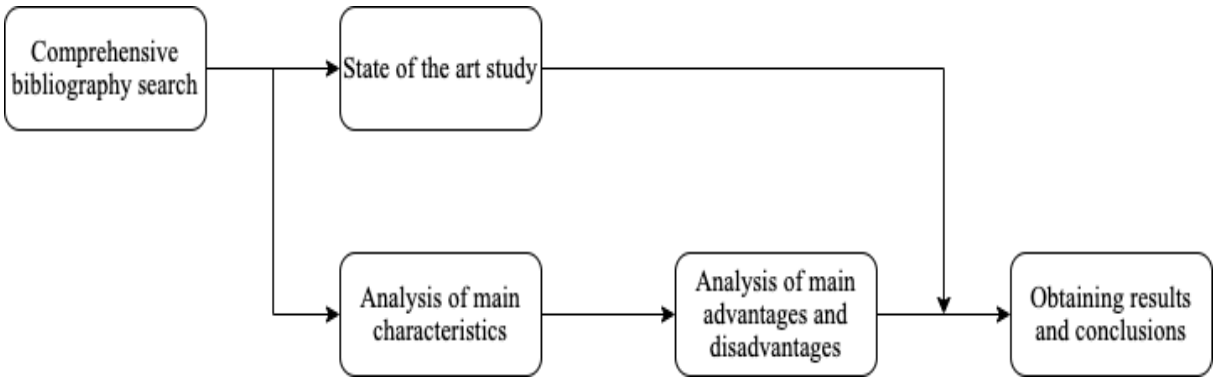

Figure 2. Scheme of the used methodology.

3. Literature review

Firstly, the different articles and studies obtained in the study of the state of the art have been collected and summarized in Table 1 and Table 2. This has been intended to verify the state of development of the technique at the time of carrying the study.

Table 1. General description of studios that will evaluate life cycle of products in the healthcare field.

	Reference	Journal	Country	Object of study
Compounds	Sherman *et al*. (2012) [26]	Anesthesia & Analgesia	United States of America	Anaesthetic drugs
Packaging	Goellner & Sparrow (2014) [27]	International Journal of LifeCycle Assessment	United States of America	Shipping containers (thermically controlled)
	Grimmond & Reiner (2012) [28]	Waste Management & Research	United States of America	Sharps containers
	Belboom *et al*. (2011) [29]	International Journal of Life Cycle Assessment	Belgium	Drug packaging alternatives (glass vs. polymer vials)
	McGain *et al*. (2010) [30]	Anaesthesia and Intensive Care	Australia	Drug trays

Table 2. General description of studies that will evaluate life cycle of processes in the healthcare field.

	Reference	Journal	Country	Object of study
Medical treatment	Thiel *et al*. (2017) [31]	Journal of Cataract & Refractive Surgery	India	Cataract surgery
	Thiel *et al*. (2015) [32]	Environmental Science & Technology	United States of America	Surgical procedure (Hysterectomy)
	Campion *et al*. (2012) [33]	Science of the Total Environment	United States of America	Birth (caesarean, vaginal)

Disposal	de Oliveira-Schwaickhardt *et al*. (2017) [34]	Science of the Total	Brazil	Treatment of hospital laundry wastewater
	Ali *et al*. (2016) [35]	Journal of the Air & Waste Management Association	Pakistan	Solid waste treatment
	Igos *et al*. (2013) [36]	Science of the Total Environment	Luxembourg	Wastewater treatment scenarios for reduction of pharmaceutical
	Igos *et al*. (2012) [37]	Science of the Total Environment	Luxembourg	Wastewater treatment scenarios for removal of pharmaceutical residues
	Köhler *et al*. (2012) [38]	Journal of Hazardous Materials	Germany	Wastewater treatment scenarios for removal of pharmaceutical residues
	Sánchez-Barroso *et al*. (2020) [39]	International Journal of Environmental Research and Public Health	Switzerland	Potential savings in DHW facilities through the use of solar thermal energy in the hospitals
Construction and maintenance	González-Domínguez *et al*. (2020) [40]	Applied Sciences	Switzerland	Scheduling of preventive maintenance in healthcare buildings using Markov Chain
Construction and maintenance	Garcia-Sanz-Calcedo *et al*. (2020) [16]	Journal of Building Physics	United Kingdom	Assessment of the global warming potential associated with the construction process of healthcare centres
	Garcia-Sanz-Calcedo and Gómez-Chaparro (2020) [41]	Sustainable Cities and Society	Netherlands	Quantitative analysis of the impact of maintenance management on the energy consumption of a hospital

As it can be observed in both tables (Table 1 and Table 2) very few studies related to the construction or maintenance of healthcare buildings have been carried out. These show how, thanks to the application of the LCA methodology to this type of building, factors such as environmental impact or global warming can be reduced. Energy efficiency has also been favoured. Analysing the studies carried out in this aspect, it has been observed that studies based on LCA of processes are predominant. Mainly stand out the ones based on disposal (treatment of wastewater from hospital laundry, treatment of solid waste, etc ...). Among the LCA studies based on products the studies based on packaging (shipping containers sharps containers, etc ...). These small observations are of great importance, as they give an idea of the studies that are easier to publish and with the highest probability of success.

Secondly, a verification and analysis were carried out for the viability of applying this Life Cycle Analysis (LCA) methodology to healthcare buildings. For this, a study and analysis of the diverse bibliography in the building field was mandatory. In Table 3 it is gathered all this bibliography.

Table 3. General description of studies that will evaluate life cycle in the building field.

Reference	Journal	Country	Object of study
Anand & Amor (2017) [42]	Renewable and Sustainable Energy Reviews	Netherlands	Recent studies, future challenges and new investigation lines of LCA in buildings
Rivela & Bedoya (2007) [43]		Italy	LCA as a tool for the identification of advantages for the bioclimatic architecture
Zabalza *et al*. (2013) [44]	Energies	Switzerland	LCA as a tool for the eco design of buildings
Buyle *et al*. (2013) [45]	Renewable and Sustainable Energy Reviews	Netherlands	Life Cycle Assessment (LCA) in the construction field

With the analysis and the interpretation of this bibliography collected in Table 3, it was aimed to gather all the advantages and drawbacks that the LCA methodology provides for its application in healthcare buildings.

According to Zabalza *et al*. [44], the Life Cycle Analysis (LCA) methodology can be used as a tool to evaluate the energy savings. As well as outstand the most influential variables in the environmental impact of a building with the objective of selecting the most suitable sustainable building shape. What is more, they indicate that the main limitations of the methodology were the complexity and the uncertainty (subjectivity) of the method, whose origin is located fundamentally in the low reliability and the subjectivity of the inputs.

Anand and Amor [42], propose to combine the LCA with BIM to take place to areas with great potential which will generate future lines of investigation in the building sector. On the other side, they suggest the need of integrating LCA certification tools in buildings. This is due to the fact that a high degree of energetic certification does not come necessary along with a lower environmental impact.

Rivela and Bedoya [43], point to the LCA strategies that, applied to buildings, they do not only provide a great reduction in environmental impacts but also, they generate a reduction in operative costs. For which make them even more worthy the performance of the project, making an enhancement of the organization image.

Finally, Buyle *et al*. [45], affirm again that the LCA is a powerful tool to evaluate the environmental impacts. Even more, they ensure that the application of LCA in the construction/building sector generate a strategy for the reduction of environmental impacts and the energy consumption.

The main characteristics of the sanitary buildings have been extracted from this information. From this process the Table 4.1 is born, in which it portrays the most meaningful advantages and drawbacks obtained once applied the LCA method in healthcare buildings.

Table 4. Advantages and drawbacks obtained once applied the LCA method in healthcare buildings.

Advantages	Drawbacks
Reduction of the environmental impact generated in the selection of systems, processes, etc	Complexity of the study development
Generation of a tool for planning environmental strategies, policies and programmes	Subjectivity in the study development
Generation of a tool for the evaluation of energy savings (Energy Efficiency)	
Selection of alternatives for proper waste management and sustainable construction	
Comparison between the functionality of products with similar characteristics	
Evaluation of the effects produced by the consumption of resources in the facilities	
Improvement of the organization's image	
Creation and development of future research programmes	
To provide the different populations with information on the environmental characteristics of the elements and systems used	
Reduction of the total environmental impact generated by the building's construction project, which in turn translates into a reduction in costs	

As it can be seen in Table 4, the advantages of applying the LCA methodology in healthcare buildings predominate over the inconveniences. This shows the significant importance of applying this analysis to this kind of building.

4. Results and discussion

Among the different studies, tasks and projects the following advantages have been found: generation of a tool for the evaluation of strategy planification, environmental programs and policies, generation of a tool for the evaluation of energy savings, selection of alternatives for a correct waste management and sustainable construction and reduction of the total environmental impact generated by the building construction project.

All these advantages have not only an economic benefit, but also considerably reduce the levels of emissions and environmental impact. This is translated into a sustainable construction that, in addition to materializing in an effort to maintain the planet with sustainable development ethics, it helps to improve the image of both the company or organization in charge of the construction project and the company that owns the building.

The major drawbacks of this type of study are its high degree of complexity and subjectivity. On the one hand, the subjectivity of the LCA depends mainly on two factors. The first factor is associated with the individual who performs the analysis or study, since there is no defined analysis process. The second

factor is associated with the low degree of reliability of the input data of the LCA method, since there are no standardized libraries of life cycle inventory, therefore, this is done at the discretion of the researcher. On the other hand, the complexity of this type of study is given by the high degree of knowledge required for its elaboration.

Some of the solutions proposed for the improvement of these disadvantages are: the standardization of the LCA methodology, the creation of a guide for the application of the methodology, the realization of LCA training courses, the use of probability distributions, etc.

The importance of this communication has been demonstrated on more than one occasion, since it offers a clear vision of the advantages and disadvantages obtained in the application of the LCA methodology to the construction of a healthcare building. This importance lies mainly in being able to verify that the application of this methodology generates great benefits on an economic, ethical and social level.

Furthermore, it opens up the possibility of developing future studies and lines of research, such as: the generation of environmental impact reduction indicators, the improvement of existing techniques, the quantification of the benefit of applying LCA in healthcare buildings, the development of new products, techniques and systems that are more respectful of environmental impact, etc.

5. Conclusions

This analysis of different case studies indicates a growing attention to sustainability in the construction sector. Current regulatory frameworks are being developed to facilitate the implementation of environmental performance assessment. Despite some limitations of the LCA technique, it remains a powerful, science-based tool for assessing environmental impacts. It can be observed that the application of the LCA study to the construction of a healthcare building generates a great number of advantages such as the reduction of the total environmental impact generated by the construction project. This will not only have a social benefit, since it improves the image with respect to competitors, but it also generates an economic benefit that will normally be associated with the reduction of waste generated and operating costs.

Different solutions have been proposed to reduce the negative impact generated by subjectivity in the application of this methodology. To this end, the standardization of the LCA methodology or the creation of a guide for the application of the methodology is recommended. Furthermore, to increase the degree of confidence in the results, it is advisable to pay more attention to the use of probability density distributions instead of deterministic values. It should also be noted that, in order to reduce the degree of complexity, solutions such as formative courses on LCA methodology are proposed.

Finally, there are many advantages to be gained from applying the LCA methodology to healthcare buildings. Among the most important there are: the reduction of environmental impact, waste and operating costs, and energy savings. All these advantages translate into sustainable construction. It is a characteristic of vital importance, since it contributes among other things to energy efficiency and the reduction of emissions. Therefore, contributes to the maintenance of the planet.

6. Acknowledgements

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