RENOVATION OF BULDINGS: REVIEW OF APPROACHS AND THE EVALUATION OF THE ENVIRONMENTAL IMPACT THROUGH LIFE CYCLE ASSESSMENT

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ABSTRACT

Nowadays, renovation of buildings is a general recommendation in order to reduce the operational energy consumption and their emissions associated. Besides, the renovation of buildings allows reusing materials, increasing the building life service and avoiding the deconstruction and new construction impacts. However, it is necessary to be aware that the intervention itself generate an impact (embodied energy, transportation and construction process), and sometimes, energy systems upgrading does not mean a consumption reduction and it also have influence on the city metabolism.
The European Union and the Royal Institute of British Architecture have defined strategies in order to reduce the impact associated to buildings through renovations or refurbishments, however, both approaches have differences in their own standpoint. Besides, there are many concepts and terms associated to renovation that do not allow to clarify the objective with a technical and rigorously perspective. Facing the current uncertainties, life cycle assessment technique allows focusing on an already confirmed methodology in order to evaluate the potential environmental impacts associated to the renovation of buildings.
While environmental impact on new construction is highly addressed, publication of refurbishment's environmental impact is lacking in the academic literature. The used materials in construction phase of conventional building accounts for 20% of the total life cycle impact, while the operation energy is around 80%. However, recent researches show how as we design buildings with lower energy consumption the previous balance is levelling, and thus the weight of the materials on the total impact of the building is around 40% compared to 60% of operating energy.
Therefore, in this communication are shown the current approaches and concepts in an international context to define a low environmental impact renovation. Firstly, it is proposed a classification of the renovation impacts according to the rebound effect theory. Secondly, it has been done a review of the academic literature that has used the life cycle assessment to evaluate the renovation of buildings, where convergences and divergences has been found between authors. Finally, it concludes highlighting those common perspectives and what fields are needed to develop in order to get a holistic and global approach of the environmental impact of renovation of buildings.

Keywords: Renovation, life cycle assessment, environmental impact, rebound effect.

1.- Introduction

Environmental protection awareness is increasing every day, because of that, in the construction sector the building renovation is a general recommendation instead of producing new ones. However, unlike new constructions that are widely researched, environmental impact associated with building renovation process and materials is hardly investigated.

To analyse the material, construction system or even a whole building environmental load, the Life Cycle Assessment (LCA) technique is commonly accepted. LCA evaluates potential impacts to the environment of process or materials, and it is defined in the ISO 14040:2006 and ISO 14044:2006 standards [1], [2]. Its application in architecture is rising each day.

Since the end of 20th century, the environmental impact of many buildings around the world have been evaluated: Sweden [3]; United States of America [4]; Japan [5]; France [6]; New Zealand [7]; Spain [8], [9]; China [10]; Scotland [11]; Switzerland [12]; Greece [13] o United Arab Emirates [14]. The use of the LCA technique is the common factor of all of them.

There are some significant reviews relating to building’s environmental impacts that make a comparison of more than fifty cases, what sheds light on this issue [15]–[17].

Those papers show how the relation between materials embodied energy and the operating energy (the energy needed to maintain the building and stand comfort conditions) is around 20%-80% respectively. However, it is outlined that the global tendency is to erect buildings with lower energy demand in the operation stage due to the internationals energy efficiency objectives, thus the previously relation (20-80) is changing to 40% of the impact associated to materials and 60% belonging to the operational stage. Therefore, it is observed that if research’s objective is a lower energy building at the end of it whole life cycle, then operating energy is reduced by adding more insulation, passive solar devices to gain or loss heat, more efficient installations, etc. what means indirectly increase the impacts associated to the materials stages.

Nevertheless, as opposed to the research carried out on new buildings and in spite of the fact that building renovation is highly recommended, building renovations is hardly evaluated through the LCA technique. It is a widespread idea that this interventions on buildings save CO2 emissions due to the materials reused, and that energy retrofits reduce the energy consumption (due to active or passive measures of interventions and new energy efficiency systems). However, it has to be aware of the impacts due to the direct, indirect and aggregated effects. Also, it is usual practice to keep the shape, orientation and windows positions when building renovation is carried out. That practice means a limitation to the most favourable bioclimatic strategies for a certain place, unless an intensive intervention were proposed, what would increase the environmental impact. Consequently, is it possible to sustain that any renovation has a lower environmental impact than a new building? Where is the limit? And, how close or far are currently renovations?

In conclusion, to declare that building renovation is the lowest environmental impact option has to be valued, and their loads have to be evaluated in comparison with the benefits.

2.- Definitions

To define the environmental impact objectives regarding to the construction sector, and specifically in building renovation, it is necessary to know how different international institutions are taking the initiative and what concepts are the using.

The European Commission sent the 1st July of 2014 one communication to the European Parliament titled “Opportunities for the resource efficiency in the construction sector” [18]. In this communication, the commission recommended the building renovation through higher resource efficiency, what would require more policies that include the wide variety of environmental impacts in the material’s life cycle.
Another interesting report published by the European Commission was the draft of the 2014-2015 Work Program for Horizon 20/20 in the area of “Secure, clean and efficient energy” [19]. This document established that the building renovation rate represent more than the 17% of the UE energy save potential up to 2050. To achieve this long-term savings, a rate of 2-3% per year of building renovations should be done, despite currently this rate is the 1,2%. To succeed, it is outlined in the document that is necessary to reduce costs and increase the speed works of the renovation measures in order to minimize the user’s annoyance.
In the previous document, the European Commission set the objective of a Holistic and Deep Renovation. These characterizations are new terms applied to the building renovation, and are defined as:

- *Holistic* – Considering all the refurbishment possibilities at building level together with opportunities at district level such as biomass, geothermal, district heating, etc. [19].
- *Deep* - Deep renovation should lead to a refurbishment that reduces both the delivered and the final energy consumption of a building by a significant percentage compared with the pre-renovation levels (Directive 2012/27/EU on Energy Efficiency) [19].

Energy consumption reduction due to Deep Renovation is controversial due to the ambiguity and lack of quantitative precision in the previous document. Basically, it is understood that energy reduction include the heating, cooling and lighting systems as well as others home electronic appliances, and is necessary to achieve a 75% of reduction in comparison with pre-renovation levels [20]. The 75% limit is a high threshold that often is difficult to achieve through interventions just in the buildings, what suppose a challenge to reach the 2050 objectives.
At the same time, within the scientific and theory literature can be observed recurring and varied terminologies in this field: retrofitting, refurbishment, renovation, repair or restoration, in English, or in Spanish *rehabilitación, renovación, reparación* o *restauración.*
The use of each word is sometimes misleading in research papers or institutional reports, what cause an obstacle for the penetration and assumption of the each concept.
The term refurbishment (*rehabilitación* in Spanish) is used in English as well as renovation. The European Commission use ‘Holistic and Deep Renovation’ in the communication previously mentioned [19] regarding to a building operation that consider both a significant energy reduction and a district energy systems.
However, those energy reduction measures in general are based on installing insulation on the envelope as a passive strategy, or by installing new efficient equipment as an active measure. This kind of buildings interventions that add new materials or elements which was not located there from the original building is called specifically ‘retrofitting’. It can be said that renovation or refurbishment use to include retrofits measures but also include other improvement, like aesthetics or spatial enhances of the building or a room.
Finally, other terms as repair (*reparación*) or restoration (*restauración*) are referred to the action of return a function or use specific to an element or equipment. The restoration, technique often used in historic buildings, means return something to its

original state, whereas the repair means return a function but some materials or systems can vary from its original state.
Besides the previous discussion, other significant institution, the RIBA (Royal Institute of British Architecture) establish the 'Principle of Low Carbon Design and Refurbishment' in one of its reports of 2012 [21]. The aim of this principle is easy to understand but is vaguely explained in the document and is unknown the boundaries of the definition, as well as is happening with the Nearly Zero Energy Buildings or Net Zero Energy Buildings (nZEB). Setting these boundaries and define properly what has to be included is important in order to be able of compare different researches. If every research does not include the same group of materials and process, unalike values will be obtained, and so generate uncertainty among technicians and generate mistrust on quantification techniques. However, the RIBA does define that for making the evaluation, it would be necessary a whole life cycle assessment for this designs and refurbishment.
In response to the RIBA initiative, a paper was published on 'Low Carbon Housing Refurbishment (LCHR), is a step forward to the definition and application of this Principle, specifically among residential buildings [22].In this paper barriers and possible initiatives to promote this kind of refurbishments under the architects point of view was studied.
In conclusion, efforts to settle down an environmental reduction impact objective in the construction sector is highlighted, and more specifically through the building renovation. Despite LCA is now beginning to be used as a technique to evaluate the environmental impact, there are ambiguity yet regarding both to the terminology and to the objectives. The proliferation of terms and tools mean an added difficulty to technicians.
Thus, a clear objective and terms definition is important to be able of settle down a roadmap agreed by the scientific community, professionals and lawyers, and so will be possible to access with security and confidence to stable and necessary funding institutions.

3.- Methodology and objectives

Once that concepts and differences of the renovation of buildings has been exposed, the main objectives set for this communication are: to classify in an orderly way the impacts associated to the renovation of buildings, and secondly, to evaluate how has been addressed this issue through the life cycle assessment.
For those purposes, firstly a categorization of the environmental impacts has been exposed according to the three levels of the rebound effect: direct, indirect and aggregated effect, which allows address the renovation of building with a holistic approach.
Secondly, the relevant aspects of the life cycle assessment (LCA) technique have been pulled out regarding to new buildings LCA that mean a change of perspective.
It has been used references that justify the necessity of research on the different environmental impact levels under a global perspective in order to make decisions.

4.- Rebound effect in building renovation

Above, it has been referenced that the saving energy potential by building renovations is around 17% in Europe up to 2050 [19].To analyse those data, it is necessary to know about energy saving as well as the impacts associated to the measures, what is called the 'Rebound Effect', and known as 'Jevons Paradox'. This is included in the energy consumption estimations models and its emissions associated at the global level [23].

This paradox was formulated in the middle of the 19th century regarding to the efficiency achieved by the new Bessemer and Henry Cort blast furnace. The introduction controlled of oxygen in the blast furnace allowed reducing the amount of carbon in order to get high temperatures in the industrial processes, thus it was possible to reduce costs. Because of the reduction of costs, the industry sector expanded and installed more blast furnaces what cause the increase of the global consume of carbon. The economists Laurent and Cacheaux analysed this paradox in a building renovation large scale, considering the rebound effect in the reduction cycles of the energy consumption due to the innovation on the systems efficiency. And it was included in the report “Policy options for carbon taxation in the EU” [23].
Specifically, the rebound effect is divided into: direct effect, indirect effect and aggregated effect [24]. Following, it is exposed a self-categorization connecting the impacts associated to the renovation of buildings, which it are not used to take into account in a complementary way for the make decisions.

4.1.- Direct effect
The direct effect is defined as the more efficiency of a type of energy resource or energy service; the more consumption of this type of resource or service. It means that if houses are more energy efficient, then occupiers would have to pay less to be in the same comfort conditions as before. Thus, some users will demand more energy because the bill is also reduced, so regarding to their incomes they can buy more energy.
This effect is included among the different scenarios calculated on energy reduction by Laurent and Cacheaux [23].

4.2.- Indirect effect
The indirect effect refers to the energy resources or to the associated impacts to all the necessary material and works to make a building renovation. Material’s manufacturing, transportation and the processes to its installation lead indirectly to an impact on the environment even though subsequently the building will consume less energy.
In the few existing papers this is the most considered effect through LCA in building renovation. At the beginning, all the impacts regarding to the use stage was called as ‘recurring embodied resource and environmental effect’. Later, in 2006, it was differentiated between the resources and impacts associated to maintain the comfort conditions in the building and those necessaries to the repair, substitution and refurbishment of the building. Below both concepts are described:
(1998) Recurring Embodied resource and environmental effects: those incurred over the effective life of the building\ including both those associated with the refurbishment and maintenance of the building and those to operate the building [25].
(2006) *Operating energy VS Recurring embodied energy* [15]:

- *Operating energy*: Energy used in buildings during their operational stage, as for: heating, cooling, ventilation, hot water, lighting and other electrical appliances. It might be expressed either in terms of end-use or primary energy.
- *Recurring embodied energy*: The sum of the energy embodied in the material used in the rehabilitation and maintenance stages.

In 2013, other RIBA report [26] demanded more researches on impacts generated by the building refurbishment and made the following distinctions: ‘fit-out A’ with an impact of 100kg of CO2-eq / m2 of usable space, and another higher done by the building users every five years, ‘fit-out B’, between 100 to 200 100kg of CO2-eq / m2 of usable space.

This approach is ambiguous and the author affirm that it is necessary to carry out a deeper research on how the building renovation affect in its life cycle [26, pp. 58–60].
In order to value the global relevance of this type of interventions, Yohanis et al affirmed that the embodied energy, including the recurrent energy, might be close to the operation energy at the end of its life cycle for long period of time (more than 100 years) [27].
Other example is founded in the MARIE project, this is a European project funded by FEDER 2013-2015 funds and address the energy retrofitting regarding to policies leaded by the public administration. In its report [28] express that one of their boundaries is the externalities and other impacts generated due to the renovation processes.

4.3.- Aggregate effect

The aggregate effect is a wider concept that relates an increase of the system efficiency to an increment of the productivity, thus it generates an increase of the economy demanding more resources and generating new impacts.
This last effect is more complex to distinguish, and connect environmental, economic and social effects.
The aggregate effect in building renovation has to be analysed from a larger scale, and considering that the building conservation means confirm the urban metabolism and morphology. Recently, the RIBA published a report on the energy consumed by buildings and its CO2-eq emissions. In this report, the author listed three main impact factors attributable to the building: embodied energy of their materials, operating energy to maintain it functions, and the energy needed to get the building [26]. So, not only embodied and operating energy must be considered, but is necessary to take into account the energy needed by the transport used to get the building. Under this point of view, building renovation means to keep a stress point in the city. If the place is not accessible by public transport, then would be needed the private vehicle to users get the building. The report's author asks himself if: "would be better an inefficient building in the centre of London? Or, otherwise would be better a very energy efficient building and with sustainable materials on the outskirts of a low dense city?" Therefore, in order to answer successfully to the building renovation under the environmental perspective, it is necessary to go beyond this dilemma and consider the three factors: the building location, their materials and its operation requirements in order to obtain a global and accurate evaluation.
A communication about the renovation of the Canfranc railway station make the reflexion about those impacts associated to the building program which is defined and the intensity of it [29]. This communication takes into account the materials impact and value the influence of the later occupancy, under this perspectives, the more intensive and complementary programs and the more people use of the building, the better building exploitation and meeting of citizens necessities.
In conclusion, before the renovation of any building its direct, indirect and aggregates effects should be considered, what means not only the impact of the building but also the synergies generated around it.

5.- LCA methodology for building renovation

As seen from the above discussion, associated environmental impacts to building renovations implies beyond energy saving benefits but direct, indirect and aggregated effects that has to be considered.
Potential environmental impacts of a system are quantified by the Life Cycle Assessment (LCA). The LCA technique is recognized by European and Spanish Norms in the UNE-EN ISO 14040 [1] y UNE-EN ISO 14044 [2]. Some authors argue

that the construction sector faces additional challenges than other sectors for evaluating its product life cycle [16], [30]. Those challenges are:

- Specific impacts in a different location in every research (construction works).
- Modelling complexity of all the intertwining products.
- Uncertain scenarios due to the ignorance of how the building will be used by occupants.
- The complexity of the indoor air quality assessment.
- Inclusion of data about recycled and non-industrialized materials.

Due to this complexity exposed, some authors [30] suggest not using a lineal and static approach, which is defined by the European Norm UNE-EN 15978- Assessment of environmental performance [31], but a Dynamic Life Cycle Assessment (DLCA). In opposition to the current methodology, which starts with the materials, construction, use (including maintenance), and finalize with the end-of-life stage, it is proposed an approach based on possible delivered services scenarios as a functional unit. This LCA perspective considers the possibility of changes in any of their stages, such as variation of the energy mix emissions factor. Because of the uncertain of the operation of the buildings, they should be evaluated as a supplier of dynamic services that can change according to some scenarios (i.e. the occupant usage periods or to the retrofit measures). In 2012, the DLCA methodology was used by Colligne, O. [32] for an institutional building and the possible evolution scenarios of the renewable energy percentage of the energy mix.

5.1.- Scenarios based methodology.

In opposition to new buildings, the distinctive aspect of building renovation LCA is that different solutions are often evaluated (from 3 to 5) in order to select the most appropriate [33]–[35]. Consequently, it could be categorized as a dynamic methodology, what is defined as:

- Dynamic Life Cycle Assessment (DLCA) as an approach to LCA which explicitly incorporates dynamic process modelling in the context of temporal and spatial variations in the surrounding industrial and environmental systems [32].

This methodology permits adapting the variation in the building renovation due to the occupant behaviour regarding to the building usage periods. Some researchers have highlighted that building usage periods given by energy modelling software may differ significantly from real occupant behaviour. The book published among the EFFICACIA and AMEC project, in the University of Seville, shows how it is necessary to characterize the occupation patterns and behaviour from the south of Spain [36].
A dynamic methodology allows doing a LCA based on different and possible scenarios, and therefore choosing the option with the best results with a global perspective.

5.2.- Indicators

Environmentally LCA and building renovation indicators used often in publications are energy consumption and CO2-eq emissions.
In particular, regarding to the carbon dioxide emissions are GWP (global warming potential) [33]–[35], [37] or Climate Change [38]. Regarding to energy resources CED (Cumulative Energy Demand)[34], [35] or GWR (Gross Energy Consumption) [33] are used. In few papers [38], others categories can be founded, such as eutrophication, acidification, photochemical oxidation potential or biodiversity.
Besides, those indicators are not often shows equally, but it is frequently to make the average impact per year in function of the estimated service life, such as CO2-eq/year o MJ/year.

To encourage the comparability between different researches, it is necessary to use the same indicators with similar modelling methodologies. Otherwise, it would not be possible to make assertive comparisons due to the existent uncertainty, and therefore it would be difficult to obtain useful information.

5.2.1.- Synthetic indicators

Besides the previous indicators, building renovation researches include often others which are elaborated by the authors in order to interpret the results. Most of the contributions are quite interesting as comparison tools for evaluating the proposed intervention's measures. However, there is a huge disparity among different research indicators due to the newness of this kind of researches and the lack of publications that reflects on this issue.

The following indicators can be founded: *marginal life cycle cost*, *marginal life cycle carbon footprint* and *Repaid invested carbon* [34]; *Payback* and *Energy Return Ratio* [35]; *Environmental Performance Ratio*, *Economic performance* and *Sustainability performance* [37]; and finally *Environmental pay-backl person* [38].

To ratify the necessity of transdisciplinarity among different areas, the *Integrated Research System for Sustainability Science* (IR3S) published the 8th august of 2014 an special feature titled: '*New directions in sustainability science: promoting integration and cooperation'.* In this report was outlined the necessity of an holistic approach and the integration of the different levels of government [39].

5.3.- Combination with others environmental techniques

Within the building renovation's environmental literature other quantifying techniques can be founded, such as the paper that compare the Ecological Footprint with LCA [40]. This research shows three categories: embodied carbon, embodied energy and ecological footprint.

The proliferation of many environmental tools has been discussed by Finkbeiner regarding to the recent European Commission's initiatives [41]. This international institution is working on a project to certificate *green products*, which methodology is based on a new proposal of 'Product Ecological Footprint'. Finkbeiner argue that this proposed methodology implies a breakdown with previous and existing tools, what means generating uncertainty to a process still under construction.

However, because the process is currently being developed, might be the moment to improve it with all the possible elements. Environmental impact is a wide concept that includes multiple components, so an extremely complex and subtle has to be used in order to encompass all factors. LCA has the structure needed to include many impacts categories of different nature.

6.- Results

A research on environmental impact associated to building renovation has been presented in this paper, and how it is addressed by Life Cycle Assessment (LCA).

First of all, it has been observed that there are different objectives leading the building renovation through different internationals institutions. On one hand, the European Commission defines a Holistic and Deep Renovation, and on the other hand, RIBA define a Low Carbon Refurbishment (LCR). The main difference is that one refers to reduce building's energy consumption (Deep Renovation) while the other implies CO2 saving emissions (LCR). Both approaches lead to finally reduce environmental impacts but with different focus.

The environmental impact associated to building renovation is composed by: direct effect, indirect effect and aggregated effect. This categorization of impacts include the consequences due to the rebound effect, that are those impacts related with

building renovation, normally not clear revealed but still associated. Under this perspective are described the impacts associated to the energy systems' efficiency, materials' embodied impacts, and those aggregated impacts associated to the needed transport to get the building once renovated.
Relating to the methodology, it can be observed how does exist differences in comparison with new buildings. It is interesting to use a dynamic life cycle assessment that allows comparing between different scenarios. Besides, used indicators are different between researches what make more difficult to relate the results. New indicators are appearing among building renovation researches, such as *marginal life cycle carbon footprint, Repaid invested carbon, Energy Return, etc.*

7.- Conclusions

Researches on building renovation's environmental impact are everyday more faced, and for doing so, life cycle assessment (LCA) technique is starting to being used.
Firstly, this paper has compared the different objectives established by European Institutions that are working on building renovation and environmental impact, as well as has been defined some terms used in this field. Besides, it has been proposed the classification of direct, indirect and aggregated effects that have to be considered when evaluating the environmental impact associated to building renovations. It is needed henceforth to keep moving forwards in the knowledge and proposing a methodological approach to the building renovation's environmental impact.
To do a comprehensive research, it has been used the LCA technique as the best option to evaluate the different possible scenarios. Therefore, it has been proposed to use a Dynamic Life Cycle Assessment (DLCA) as a technique able to consider a wide amount of effects, such as renewable energy possible scenarios in energy mix, climate change effects or occupants usage patterns.
In a literature review, it has been observed that current methodologies and indicators vary significantly among different papers. Compiled indicators are considerable contributions to evaluate deeply the environmental impact associated to renovations. However, it is necessary a consensus on what are the most appropriated ones due to its proliferation, otherwise, we are under the threat of obtain many incomparable researches.
Finally, it is outlined that there is lack of comparatives researches between new buildings and renovation indicators; therefore, it could be possible to affirm what renovations are the best option in order to reduce the impacts generated by construction sector to the ecosystems.

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