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Is building renovation truly sustainable? The need for applying a multi-criteria assessment through life cycle approach

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Abstract: The aim of the present research is to characterise the international scene in the field of building refurbishment, by thoroughly reviewing the literature relating to building renovation and systematising the results according to the different aspects considered by the authors. Even though there is certain consensus with respect to the criteria for the selection of energy efficiency measures, the assessment criteria differ broadly and widely. The present work highlights the lack of consensus on the assessment criteria and the need of harmonization. A holistic view is required in order to identify the most sustainable strategies in each particular case, considering social, environmental and economic impacts from a life cycle perspective.

Building renovation, energy efficient retrofits, assessment method, sustainability, energy efficiency.

1. **Introduction**

Buildings worldwide account for 16-50% of total energy consumption, while the corresponding value in Europe is 40%. Although over 70% of the existing building stock is inefficient, the replacement rate of existing buildings is just around 1.0-3.0% per year. The challenge is now to act on this stock, the result of the heavy need for housing in the middle of the last century, after the devastation of World War II.

Nowadays, the need to promote energy efficiency in the building sector is widely recognized. Following the European commitment of “Horizon 2020”, many governments and international organisations have made significant efforts towards energy efficiency improvement in existing buildings. In a previous work, an analysis of over 50 renovated residential buildings in Madrid was carried out, with the conclusion that the same energy efficiency strategies had been applied in buildings with different features. Furthermore, only the reduction of thermal transmittance values was evaluated. Since as yet there has been no deep analysis of the same, further study is needed together with fixing the priority of evaluation of the sustainability of measures applied.

The aim of the present research is to characterise the international scene in the field of building refurbishment, by thoroughly reviewing the literature relating to building renovation and systematising the results according to the different aspects considered by the authors. Even though there is certain consensus with respect to the criteria for the selection of energy efficiency measures, the assessment criteria differ broadly and widely. Some authors consider solely environmental aspects, others analyse exclusively economic factors and others develop multi-criteria methodologies considering both environmental and economic aspects. However, the life cycle approach is not considered in either the economic or the environmental assessments. Apart from this, there is a highly limited number of authors who evaluate the social dimension.

2. Building renovation: is it truly sustainable?

The amount of research carried out in building refurbishment has significantly increased over recent years. In the present work, a systematic classification has been done in order to identify the most common energy-efficient strategies concluding that retrofit strategies implemented are quite similar in all the case studies analysed. One central question that should be addressed is: is building renovation truly sustainable? The assessment criteria and methodologies differ broadly and widely. For the purpose of this study, sustainability assessment works have been classified according to the evaluation criteria: environmental, economic and multi-criteria.

2.1. Environmental assessment

During the past decade several studies have researched the efficiency of energy saving measures for residential buildings. Annual energy savings and CO_2 emission reduction were only considered until a few years ago (1,2). More recently, the whole life of the building has been included in the environmental analysis, as well as a broader range of environmental impacts, through the Life Cycle Assessment (LCA) method (3,4).

2.2. Economic assessment

When analysing retrofit strategies from an economic perspective, several approaches are considered, such as savings-to-investment ratio (SIR) (5), cost-benefit analysis (6), relation between investment cost and annual energy cost (7) and net present value (NPV) approach (8). The NPV approach is used for determining the present values of the costs that would occur in the remaining life of a building; it is the most common method for calculating Life Cycle Cost (LCC), as LCC represents the sum of the present value of investment and operating costs for the building and service systems, including those related to maintenance and replacement, over a specified life span. In Sweden, LCC analysis of renovation measures for all multifamily buildings is required as part of the national implementation of the first EU energy performance of building directive (EPBD) (9).

2.3. Multi-criteria assessment

Multi-criteria analysis methodologies (MC) have increasingly been developed in order to achieve sustainable assessment; economic and environmental impacts are generally considered, while social impacts are still put aside. Jaggs and Palmar (10), Rey (11), and Alanne (12) proposed MC-based approaches for the evaluation of retrofitting scenarios. Diakaki et al. (13) investigated the feasibility of applying multi-objective optimization techniques to the problem of improving energy efficiency in buildings. Juan et al. (14)

developed a genetic algorithm-based decision support system for housing condition assessment that suggests optimal refurbishment actions considering the trade-off between cost and quality. Wang et al. (15) reviewed multi-criteria/objective decision making (MCDM) methods used in sustainable energy field, namely in the selection of energy supply systems. Chantrelle et al. (16) developed a new tool, MultiOpt, for the multi-criteria optimization of renovation operations, with regard to building envelopes, HVAC systems and control strategies. Asadi et al. (17) presented a multi-objective optimization model to quantitatively assess technology choices in a building retrofit project. Brown et al. (9) proposed a method for assessing renovation packages drawn up with the goal of increasing energy efficiency; the method included calculation of bought energy demand, life-cycle cost (LCC) analysis and assessment of the building according to the Swedish environmental rating tool Miljöbyggnad (MB). All mentioned studies are however limited to the evaluation of energy consumption, costs and/or CO_2 emission reductions. It is remarkable that the overall life cycle environmental impact and cost of housing renovation have not been considered in an integrated way in the aforementioned works.

More recently, Allacker et al. (18) proposed an integrated assessment of the life cycle environmental impact and cost methodology for sixteen representative dwellings in Belgium, both existing and newly built dwellings. The environmental impact was estimated based on a life cycle assessment (LCA), while a life cycle costing (LCC) analysis was used for the cost aspect; the investment cost was also considered in terms of affordability. Vrijders and Wastiels (19) evaluated the renovation of a building in Belgium considering different scenarios through the LCC and LCA methodologies. In this case, cost efficiency and environmental impact are compared separately. De Angelis et al. (20) analyzed a multi-story residential building located in Northern Italy in order to evaluate different renovation alternatives, considering LCA and LCC approaches. Ostermeyer et al. (21) proposed a multidimensional Pareto optimization methodology, using LCC and LCA, combined with first stages of a social assessment in a feasibility study but potentially later full SLCA; LCA and LCC were used to analyze a case study from an EU project named BEEM-UP in which solutions for large scale uptake of refurbishment strategies are developed. Cetiner and Edis (22) defined an environmental and economic sustainability assessment method to evaluate the effectiveness of existing residential building retrofits for reducing their space heating energy consumptions and the resulting emissions.

3. Towards a sustainable building renovation

As innovative technologies and energy efficiency measures for buildings are well known, the main challenge is to identify those that will prove to be the more effective and reliable in the long term. A limitation observed in this review study is the difference in the appraisal criteria. The wide variety on assessment methods and tools and the lack of uniform criteria, make impossible to compare results from different research works. Table 1 shows a compilation of multi-criteria methodologies that consider both economic and environmental approaches over the whole life cycle.

Allacker et al. (18)

Economic criteria

Life cycle cost (€/m^2)

Initial cost (€/m^2)

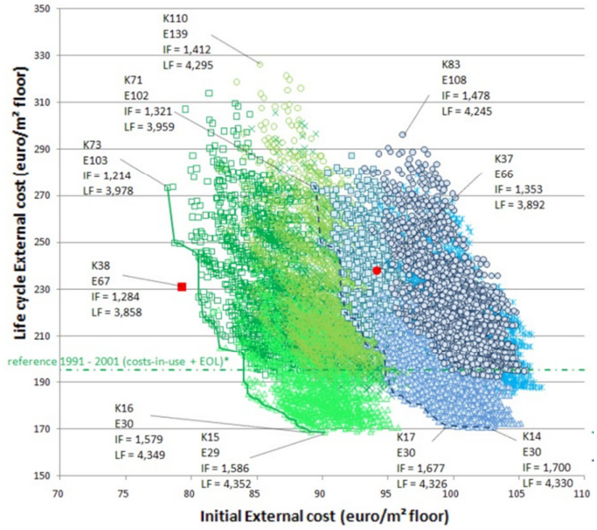
Environmental criteria

External cost (€/m^2)

External initial cost (€/m^2)

Optimization method

Pareto optimization



De Angelis et al. (20)

Economic criteria

Life cycle cost (€/m^2)

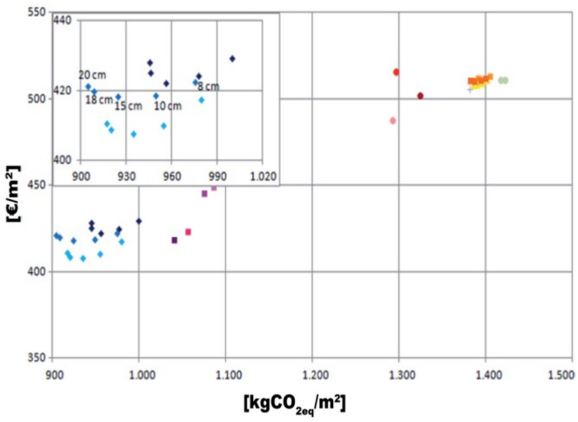
Environmental criteria

Cumulative Energy Demand (MJ/ m^2)

CO_{2eq} emissions ($kgCO_{2eq}/m^2$)

Optimization method

Pair-wise ranking method



Ostermeyer et al. (21)

Economic criteria

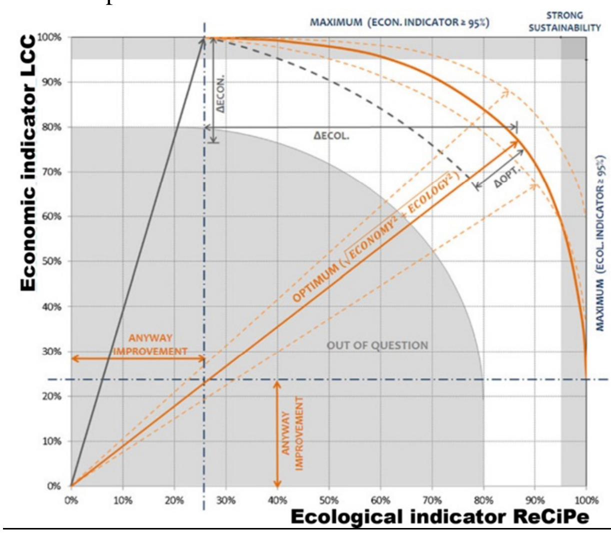
Life cycle cost

Environmental criteria

ReCiPe

Optimization method

Pareto optimization



Cetiner and Edis (22)

Economic criteria

$CR_{i,j} = (CI_i - CI_j) \times CI_i$

CR: economic performance; *CI*: economic impact (TRY); i, j: building type and retrofit alternatives.

Environmental criteria

$NR_{i,j} = (NI_i - NI_j) \times 100/NI_i$

NR: environmental performance; *NI*: environmental impact (eco-points); *i,j*: building type and retrofit alternatives.

Optimization method

Weighted-sum method

$$SP_{i,j} \quad \left(\frac{(NR_{i,j}\times m_n) + (CR_{i,j}\times m_c)}{100}\right)$$

SP: sustainability performance (−); *NR*: environmental performance (−); *CR*: economic performance (−); *m*: is the importance ratio (%).

The indices *i* and *j* are the building type and the retrofit alternative planned to be used respectively.

The indices *n* and *c* indicate the environmental and economic performances respectively. The sum of m_c and m_n is 100.

Table 1. Comparison of multi-criteria methodologies of environmental and economic assessment applied to residential sector.

In order to achieve sustainability, the whole life cycle must be considered. In buildings with high-energy consumption, operational energy represents a high percentage compared to the total life cycle energy use. Nonetheless, there is currently an increasing trend towards low energy houses and, as energy consumption decreases, energy involved in the rest of the life cycle phases become more and more important.

One major concern is that social performance is not considered yet in these methodologies. Ostemeyer et al. (21) discussed the potential for including Social Life Cycle Assessment (SLCA) as a third dimension in the methodology proposed. However, they concluded that the development in the field of social indicators in the building sector has to be strengthened in order to come up with a holistic picture and respectively with appropriate responses to current challenges. Although LCA and LCC methodologies are used in the four cases, output indicators differ significantly as do optimization methods, which prevent the comparison of different studies.

There is therefore a great need for harmonization in this area. The technical committee ISO TC 59 in parallel and in coherence with its European counterpart, CEN TC/350 Sustainability of construction Works, are working on the development of the standards for the sustainability assessment of buildings, including the assessment of environmental, economic and social performance. The framework under development applies to all types of buildings and it is relevant for the assessment of the environmental, social and economic performance of new buildings over their entire life cycle, and of existing buildings over their remaining service life and end of life stage.

4. Conclusions

This paper presents a critical review of the works related to the energy-efficient housing renovation and discusses the sustainability assessment methods used in building retrofits. Firstly, assessment methods have been classified into environmental, economic and multi-criteria. Multi-criteria methodologies has been deeper analyzed, briefly describing those that cover the entire life cycle (Table 1).

The concluding remarks in this area are as follows:

- There is a certain degree of consensus about energy-efficient strategies in housing renovation. Envelope insulation and windows replacement are the most common measures, as they are good passive strategies in order to reduce heating energy demand.
- There is not any unanimity on the sustainability assessment criteria. Although multi-criteria methodologies have become increasingly popular, they do not consider economic, environmental and social issues simultaneously in the entire life cycle.

- The different normalization and weighting methods not only reduce the transparency of the study, but also make the results uncertain and subjective. Moreover, results cannot be compared.

To sum up, more research should be developed on multi-criteria methodologies, as a decision tool in order to compare the sustainability of alternative solutions on refurbishment projects.

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