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Economic and environmental savings of structural buildings refurbishment with demolition and reconstruction - A Portuguese benchmarking

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ABSTRACT

Europe is a consolidated continent, characterized by a wide range of ancient buildings that urgently need refurbishments, especially in seismic zones such as Portugal, where structural reinforcement is imperative. However, demolishing and reconstructing also contributes to real estate renovation. In these cases it is simpler to build earthquake safe buildings that comply with current standards of comfort and quality. The question now is whether refurbishment (and what type) is environmentally and/or economically profitable or needed compared with new construction. To answer this question, this work used the life cycle approach in two complementary approaches: a literature review that theoretically compares different LCA works for refurbished and new buildings; and a real LCA and LCC case study for a classified ancient Portuguese building located in Lisbon, where real refurbishment is compared with hypothetical demolition, followed by complete reconstruction on the same site, respecting the same architecture, constraints and demands, and using reinforced concrete and clay brick walls. This issue is very urgent in Portugal, because of its extensive stock of ancient buildings needing refurbishment works. Moreover, there are few studies reporting whether the refurbishment can be economically and environmentally more efficient, according to the Portuguese economic environment. Thus, this study mostly contributes to this debate, first at a national level, and then as a new case study reporting this kind of benchmarking, and its significance is related to the actual results measured at the construction site for the traditional refurbishment works made in Portugal. This comparison showed that structural refurbishment seems to be environmentally more positive. Nevertheless, in the case-study gains were not as high as commonly suggested, mainly because of the massive use of structural steel and shotcrete required for the seismic and structural strengthening of the ancient building. Finally, as far as the economic approach is concerned, this paper concludes that in those conditions rebuilding would make more economic sense than refurbishing. These conclusions indicate that an integrated decision-making process is needed and also stress the development of new financial facilities for refurbishment and, especially, the development of less costly solutions that could save scarce resources and incentives.

1. Introduction

The world population reached 7 billion in 2011. That figure represents a 5 billion growth in a single century, and recent estimations indicate that this growth will continue in the decades to come [28,63]. This demographic explosion was so fast that the world could not efficiently respond to the growing global needs. Consequently, there was more industrial and economic production with less efficient regard to environmental issues [19]. This has pushed the world's ecological footprint up to 1.5 planets, largely thanks to energy consumption and atmospheric emissions [18].

The construction sector has also contributed to this pressure on the environmental. In fact, buildings represent 40% of the EU's final energy consumption, while the figure for Portugal is 29% [15]. Moreover, they are responsible for 33% of the total solid waste in the EU and 22% in Portugal [17]. But other examples of environmental impacts could be given, such as the huge waste of drinking water, which has been estimated at 66% in Portugal [2].

Therefore, designing more sustainable buildings with lower environmental impacts is a duty for engineers and architects. For this, environmental impacts and performance levels should be

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precisely quantified, preferably using a life cycle approach [22,42] that allows identifying impacts [10,47,11].

On the other hand, Portugal is facing a deep real estate crisis, characterized by a 15.4% decrease in the number of buildings completed in 2011 [34]. Moreover, the 2011 national census [31] showed that there are 1.44 homes per family and the annual average refurbishment growth national rate in the 2000 decade was 5% [34]. Thus, provided financial resources are available, the refurbishment market quota will probably rise and new construction will probably decline.

In most developed countries, refurbishment is already of major importance and can represent nearly 50% of construction market [36]. This also stresses the need for refurbishment life cycle assessments, especially in consolidated countries such as European ones [22]. Considering these findings, sustainable refurbishment is one of the developed countries' most challenging issues for future decades. In fact, it was even pointed out by Ref. [37] that this could be the most likely solution for the present real estate crisis.

Apparently, as well as any social gains, refurbishment seems to be more sustainable than demolishing and rebuilding [64]. Ireland [35] concluded that refurbished buildings could be as comfortable as new ones, with energy and CO_2 savings of up to 70% in some cases.

However, more work needs to be done to mathematically demonstrate these environmental gains, when comparing refurbishment with demolition followed by an equivalent new construction, built under the same conditions, constraints and demands.

This work is especially needed in Portugal, where a major park of the stock is made of ancient buildings needing entire refurbishments and for which it is imperative to know, from the very initial stages of the project, whether refurbishment is environmentally and economically more efficient. Furthermore, it is a contribution for abroad studies since it thoroughly reports the works done and their impacts and costs. The former ones were measured at the construction site and the latter ones precisely correspond to the budget costs of the contractor.

Therefore, this paper has been written considering two different approaches:

1. A literature review, comparing different LCA studies of refurbished and new buildings;
2. A case study analysis, applying LCA and LCC to a real classified refurbished and seismically reinforced building. These data were then compared with an equivalent hypothetical structural solution, meeting the same design requirements and using Portugal's most common construction materials: reinforced concrete and clay brick walls.

After these two complementary approaches, the paper ends with a discussion of the results, drawing conclusions as to whether refurbishment with this specific alternatives is environmentally and/or economically more profitable than building a new equivalent construction, within the boundaries of this study.

2. Literature review

2.1. Life cycle assessment methodology

The LCA methodology is described in ISO 14040 and it exactly quantifies all the environmental impacts of one product (a building, for instance). The analysis considers its life cycle phases according to its expected service life, and includes the extraction of raw materials and industrial processing, the construction phase (when the LCA ends here it is called cradle-to-gate), the operation and maintenance and the end-of-life stage (when the building is demolished and the waste is not recycled or reused the LCA is called cradle-to-grave; if the generated waste is recycled and/or reused for similar functions the LCA is called cradle-to-cradle) [25,32,33].

Table 1
Examples of LCA studies for construction materials.

Construction materials	Examples of studies
Structural materials	– Comparison of reinforced concrete with steel construction [16] – Comparison of timber structural solutions [51] – Comparison of several different structural solutions [38] – Assessment of different types of pavement [54]
Roof materials	– Traditional roof materials [1] – Innovative green roof solutions [39]
Wall-systems	– Non-structural wall systems [47,48]
Coatings	– Comparison of ceramic tiles with natural stone tiles [45] – Other studies using recycled materials [55]
Mortars	– Low impact mortars [30,44]
Thermal insulation	– Natural materials like kenaf-fibers [5] – Comparison of more traditional insulation solutions, such as mineral wool and extruded polystyrene [49] – Comparison of traditional insulation materials with other more recent ones that incorporate natural and/or recycled materials [14]
Glazing solutions	– Assessment of the benefits of wood frames [61] – Assessment of electrochromic windows in terms of reducing residential energy needs [60] – Identification of the optimum areas to be glazed in specific climates [59]
Equipment	– Comparison of different energy production systems [50] – Comparison of air-conditioner and fluorescent lamp [62] – Domestic hot water production systems [6] – Micro wind turbines [65]

2.2. Literature review

LCA is a very complete and detailed task that quantifies all the important environmental impacts of a project. It has been used widely in the scientific community to measure the environmental benefits of constructive solutions. At first, unit products, e.g. certain types of wall, insulation, or structural materials were assessed. Construction LCA analyses later evolved to encompass assessment of the entire building, seen as a general system [46].

The first group of studies, which concern constructive solutions, contains a wide range of works on different kinds of construction materials, such as the ones described in Table 1.

Our brief review of scientific LCA studies showed that the approach has been widely used to assess and compare the environmental performance of a number of solutions. It also