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Ecological footprint of the use and maintenance phase of buildings: Maintenance tasks and final results

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ABSTRACT

According to numerous studies, approximately 90% of energy consumption in the life cycle of buildings occurs during the *use and maintenance* phase. The main aim of this study is to propose a method for the detailed calculation of costs and environmental impact corresponding to this phase, thus providing useful data for Facility Managers. The organization of the consumption of resources into three fundamental elements (manpower, materials, and machinery) enables the cost to be broken down and the Ecological Footprint [1] indicator (EF) to be applied. In previous advances of this research, the development of the model was focused on the utility consumption and cleaning tasks. On this occasion, the model is completed with the handling of maintenance tasks and a detailed assessment of the results, in which the factors that mark the cost and environmental impact are identified, as well as the specific moments of this phase in which peaks occur. In order to compare the costs and impacts produced each year, economic and environmental discount rates are used with respect to a baseline year. The methodology is applied to the case of a college hall of residence that houses up to 139 guests. The results show that cleaning tasks represent 6% of the annual EF and 63% of the annual cost, and maintenance 14% and 17%, respectively, thereby justifying the need for quantification. Finally, seven tasks are identified that together generate half of the EF and cost of cleaning, and nine other actions that incur more than a third of the annual cost and EF of maintenance.

1. Introduction

Economic and environmental assessment through indicators becomes essential for efficient management during the service life of buildings. The operation of the building in the *use and maintenance* phase causes a considerable impact that should be measurable and quantifiable through economic and environmental indicators.

In recent decades, many calculation models for the environmental impact of buildings during their life cycle have been published. Most of these studies can be consulted in several recent reviews [2–5], but only those studying the use and maintenance of buildings or using the EF indicator are hereby highlighted. The high complexity of the set of activities carried out during this phase of the life cycle of a building, along with the general perception that maintenance and cleaning are not environmentally significant with respect to the utility consumption, have resulted in the estimation of these values being omitted in almost every study.

Some interesting features have been identified in previous calculation models for the environmental impact of the use and maintenance of buildings, such as the inclusion of an inflow of materials for the building maintenance during its *use* phase [6–10], the distinction between small renovations (e.g. repainting, lamp replacement, and door repairs) and the complete rehabilitation of the building, the assumption that small maintenance tasks will probably remain unfulfilled when the building nears the end of its service life, or the likely reduction of the embodied energy of materials over the years [11].

Although most studies confirm that energy consumption during the *use and maintenance* phase is by far the largest contributor (90%) to the environmental impact of the entire life cycle of the building [2,12,13], in certain cases it has been pointed out that, regarding new low-energy buildings, the relative importance of the different phases is undergoing change [14–16]. According to Huberman and Pearlmutter [17], the embodied energy can, in these cases, represent up to 60% of the energy consumption during the life cycle of the building. Therefore, with the evolution of build-

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ings towards a lower operational consumption, attention will be diverted in the near future towards the reduction of the embodied energy of construction materials.

Regarding the models of application of the EF indicator to the building sector, there are currently only a few examples. Bastianoni et al. [18] use the service life of materials to obtain their annual embodied energy, with an extra 5% as an approximation to the energy consumed by machinery for its implementation. Their model has a number of shortcomings, failing to account for water consumption, waste generation, and manpower, thus obtaining results that could easily be assimilated to the Carbon Footprint.

Bin and Parker [19] study the variation in the EF of buildings produced by energy retrofitting (thermal isolation, air containment, and use of renewable energy). Solís-Guzmán et al. [20] develop a calculation model of the EF for the *construction* phase of residential buildings, which introduces not only the consumption of water during the construction work, but also the food and mobility of manpower. González-Vallejo et al. [21,22] improve the previous model and apply it to approximately 100 buildings that constitute a representative set of the residential sector in Spain. These are classified according to typology and broken down into the different phases of the construction process, thus obtaining results that can be extrapolated to estimate the EF of similar buildings built in that country.

Teng and Wu [23] analyze the complete life cycle of an exhibition hall in Wuhan, China. Regarding the operation phase, they include the consumption of energy and water over the estimated service life of the building. In its eagerness to cover the whole life cycle, this model makes mistakes, such as assigning the impact of water consumption to the productive surface of inland and marine fishing areas.

Finally, other researchers have successfully applied the EF indicator to other life cycle phases of the building, such as *urbanization* [24] and *rehabilitation* [25]. In order to obtain a complete life cycle assessment of buildings, unification of criteria for calculations among the various models must first be accomplished.

Given the number of processes to be managed during the *use and maintenance* phase, it is necessary to have a professional Facility Manager (FM, hereinafter) to attend to the technical, economic, environmental and administrative aspects of the building [26]. This FM needs tools that ease the work and allow these factors to be optimized. Both the process and the boundaries of facility management are defined in the series of seven standards UNE-EN 15221:2012 [27], which serve as a reference frame for this professional group.

The main aim of this study is to propose a method for the detailed calculation of costs and environmental impact corresponding to the *use and maintenance* phase of buildings. The EF indicator has been selected for the environmental impact assessment due to its simplicity for the general public [28,29], as well as its capacity to support legislative and regulatory actions [30,31].

The breakdown of costs into materials, manpower and machinery as basic elements for the quantification of the resources consumed also manages to provide transparency to a business sector that, generally, due to lack of knowledge or lack of interest, has yet to be analyzed in depth. The reality is that maintenance and cleaning of buildings constitute a considerable expense, whose detail in budgets is not usually demanded to the same degree as for construction work. However, knowledge of this data would be considered of vital importance to any FM or manager of tertiary buildings.

This article presents the latest advances in the study initiated in Martínez-Rocamora et al. [32], and focuses on maintenance and renewal tasks, and final results. Reading the cited article is therefore recommended for a full understanding of the model.

The following section clarifies certain aspects regarding the system boundaries of this study. Secondly, the singularities of maintenance and renovation of construction elements are determined, and these justify the need to adapt the calculation model from the *construction* phase. These peculiarities affect the calculation of costs as well as the hypotheses and formulation in obtaining their impact in terms of EF. Finally, the results corresponding to the *use and maintenance* phase of the case study presented in the aforementioned article are shown and discussed.

2. System boundaries

The system must have longitudinal boundaries to define the start and end points of the *use and maintenance* phase. After the completion of the *construction* phase, the building is ready to be occupied, thus beginning the longest stage of its life cycle, which is usually estimated to be between 40 and 100 years. However, defining the end of the service life of a building is not so simple. For example, Adalberth [33] includes the occupation of the building, with an intermediate period for renovation, in the *use and maintenance* phase, ending with its demolition. This is a rather generalized approach, with slight variations from one study to another. For example, Blengini [13] does not specify whether there is any maintenance work on the building, thus limiting the study to energy, gas and water consumption according to statistical data from Italy.

CEN/TC 350 “Sustainability of construction work” includes maintenance, repair and replacement of products, operational energy (HVAC, domestic hot water, and lighting), and operational water consumption in the *use* phase of the building. This phase ends with the beginning of deconstruction. The standard UNE-EN 15978:2012 [34] establishes, in the first place, that the *use* phase extends from the end of the construction work until the building is about to be deconstructed/demolished.

In short, most authors state that the occupation stage of the building ends with its demolition. However, when a building is no longer habitable, we are faced with the decision of whether to demolish or rehabilitate, and it is more common to opt for rehabilitation for both economic and environmental reasons [35]. In that case, would the building, whose life has been extended as a result of the rehabilitation, be the same building? Otherwise, would this be a new building beginning its life cycle?

In response to this question, the following assumption is made in the present study: the service life of a building ends when it is no longer habitable. For the model here proposed, a building in a poor condition that is subsequently rehabilitated undergoes major changes, both in its constructive solutions through a possible energy rehabilitation and in its installations, which are modernized with the consequent changes in its consumption patterns. It could even happen that, with the rehabilitation, the building changes the type of use it was originally intended for. Therefore the building that undergoes a rehabilitation is considered as a new building that is beginning its service life [36].

In the following section, a number of peculiarities of maintenance tasks are identified regarding the definition of their corresponding costs, which will allow those tasks to be broken down into the three main components: manpower, materials, and machinery. A number of modifications in the previous methodology [32] for the application of the EF indicator to the *use and maintenance* phase of buildings are also defined.

3. Methodology

3.1. Singularities of maintenance costs

The concept of maintenance is divided, in this study, into four different activities: predictive, preventative, and corrective maintenance, and the renovation of constructive elements. The