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Embodied energy on refurbishment vs. demolition: A southern Europe case study

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ABSTRACT

Embodied energy on building materials is a concept that allows the measurement of environmental impact, considering energy expenditure associated to the extraction, transport, processing, on-site assembly and performance of materials, during their expected life cycle. Longer service life periods of given materials and derived assemblies correspond to more sustainable practices, as they reduce the impact of energy and resource consumption and the corresponding level of emissions.

In this paper, an assessment is made of the cost/benefit ratio associated to two different strategies for intervention on a 40 year old detached single house in Portugal: total demolition vs. refurbishment. Since the building cost of both strategies of intervention was estimated to be similar, environmental impact was considered as a decision criteria. Therefore, an analysis was made of the initial embodied energy, new materials and materials sent to landfill, for two different scenarios: (a) integral substitution of the existing structure by a new house, and (b) partial demolition and refurbishment of existing house. The original house was characterized to provide a benchmark for the comparison of both intervention strategies. In the end, data related to energy and mass were used to sustain a decision regarding the recommended type of intervention.

1. Introduction

All buildings are an assembly of matter and energy that fulfil a purpose during a period of time. Matter and energy are inextricably linked: building materials are the result of years of transformation of raw materials under the action of nature or of man in processes that require variable amounts of energy [1]. Energy is also consumed as building materials are assembled into components and systems that usually need to be transported and installed in the building site. Since the production and consumption of energy have known environmental impacts, energy and pollutant emissions (such as carbon dioxide), may be regarded as being "embodied" within materials [2]. After the original construction, buildings continue to change [3], consuming more matter and energy (necessary to produce, transport and assemble new materials and solutions and to dispose of existing matter). This process of inputs and outputs of matter and energy can be referred to as "building metabolism". Material consumption and embodied energy on building materials can therefore be used as indicators of environmental impact and tools for sustainable strategic decisions on regional, national or local levels.

The understanding of energy as a key-factor for sustainable development (or impact mitigation) has been expressed and demonstrated time and again. The increasing energy consumption trend and the need for energy savings are also well described in the literature. Pérez-Lombard et al. [4] show that primary energy consumption – that results from raw material consumption/burned, extracted directly from nature [5] – has grown 49% between 1984 and 2004. Considering that 85% of the world production of primary energy is based on fossil fuels (petroleum, gas and coal), it is not surprising that CO_2 emissions have increased 43% for the same period, with dire consequences to the so-called greenhouse effect and global warming [6–8]. The consumption of materials has also been rising since the First World War, with only punctual variations related to armed conflicts, major economic recessions or oil crisis [9]. The increased world consumption levels of materials raises issues related to resource adequacy and the impact on the global ecosystem [9,10]. The patterns for increasing energy and materials consumption are expected to continue: by 2035 global energy demand should have increased by 40% and greenhouse gases emissions may grow 20%, according to recent estimations from the

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International Energy Agency [4,8,11]. Presently, the construction cluster is responsible for 20 to 40% of energy consumption and for 20% of the world's fuel consumption [1,4].

Data on the amount of matter required for a given construction operation may be broken down gradually in systems, components, materials and bulk materials. The energy (as well as pollutant emissions) embodied in materials can then be used as a simplified indicator of environmental impact and used as decision support tool. With small variations, embodied energy (EE) can be defined as the quantity of energy used during the lifecycle of materials, upstream or downstream of the manufacturing of building (construction, renovation or refurbishment). Embodied energy may thus include the extraction, transport, processing of raw materials, manufacturing of building materials and components, the energy used for the supply, various processes of the in-site assembly, storage, performance, deconstruction and disposal of materials [2,5,12,13]. The estimation of embodied energy is complex, difficult and time consuming. Moreover, there is no standard methodology available and different approaches have distinct boundary definitions as to what is included or excluded in the estimation of embodied energy reference values [2,5]. Embodied energy is just a fraction of the total building energy, which encompasses more than operating energy–energy consumed by end-users, also referred to as delivered energy [5,12]. Although operating energy accounts for the majority of consumption during the life-cycle of a construction, recent studies point out the increasing weight of EE for low (operational) energy buildings [5,13–16], especially when compared to conventional buildings.

The environmental and economical impact of construction, not to mention the sheer scale of the sector, fully justifies further research on more sustainable practices for there is an "ample scope for energy reduction and carbon dioxide abatement" in the words of Hammond and Jones [2].

2. Aim of the study

In this paper, a real life case study is presented where the concept of embodied energy is used to support (more sustainable) strategic decision making on a major refurbishment operation of a detached single house, in Portugal. The authors also worked as designers, thus obtaining privileged access to primary data sources on the construction. The results obtained are compared and discussed with results from other case studies, located in colder climates and with different construction systems.

2.1. *Studied object and background*

The original house dated from the late-1960s and although the construction still responded to basic technical requirements (load bearing, water tightness), all infrastructures were deemed to be obsolete, as well as the internal lay-out of spaces. The owner also required more usable space and comfort, which led to an architectural design that enlarged the floor area, altered the interior lay-out and improved the hygrothermal performance of the whole. Total energy consumption was identified as a paramount theme, as literature revealed that up to 50% of the total energy consumption remains embodied in the materials over a 50 year life-time – the average expected design life of the operation – for a passive house [13].

Two possible design strategies were considered: (a) total demolition of the existing house and construction of a new one; (b) a major alteration of the existing house. Although the cost of materials of the former solution was deemed to be higher, it was nevertheless a competitive possibility because of construction time savings and overall lower complexity. The refurbishment solution was regarded as less expensive in terms of materials, but would require a better skilled work force to deal with the complexity of the building process and would also require a larger building period. Both solutions were deemed to have roughly the same cost.

Since the brief, architectural layout and performance specifications were the same for the two possibilities and since cost was not a differentiation factor, embodied energy (EE) of materials was used to quantify the energetic and environmental impact of both solutions. From a research point of view, this process was regarded as a miniature case study for sustainable strategic thinking and real life decision making that could provide hard data generally difficult to obtain, in line with similar research examples [17,18].

The present research also provided data related to the EE of heavy/masonry construction types in moderate climates, seldom found in literature as opposed to light/timber constructions in colder climates [19,20]. In fact, a literature review showed that most published research on EE deals with case studies in Scandinavia [14,21], central Europe [13,15], UK, USA, Japan, Australia or New Zealand [2,5,12]. In most, if not in all situations, heating is the main source of energy demand. However, as pointed out by some authors, in temperate climates design priorities can be more complex as cooling and ventilation are also important [19]. Finally, as it has been also noted, Portuguese energy consumption patterns differ from those on colder climates, since householders are not used to heating/cooling all rooms simultaneously, nor continually [20]. As a result, the average annual end-use energy consumption of Portuguese households is the lowest in Europe: 31.4 kW h/m^2 (or 2.7 kOe/m^2) [22], below other case studies [12,14]. Data for 2011 [22] show confirm the specifics of the Portuguese context, as shown in Table 1.

3. Methodology

In order to allow for the comparison of the two design strategies, three "scenarios" were studied: (a) the original construction; (b) the demolition of the original construction and the building of a new house and (c) the partial demolition of the original construction and a major refurbishment operation. For simplicity's sake, such scenarios are referred to as (a) "existing house" or scenario "E"; (b) "new house" or scenario "N"; (c) "refurbishment" or scenario "R".

For each scenario, an inventory analysis of materials was carried out. The data gathering stage is often presented as painstaking and time-consuming [2,16] as each building has a large number of components that have to be broken down to its base materials. The present work was not an exception, but an open access to information and direct knowledge of the studied object provided added-value to this stage [5]. Thus, to begin with, data was gathered on the building characteristics: dimensions were taken in the original house and the layout for interventions N and R were analysed. Since the design solution was identical, only the method of implementation differed. Second, all building materials and solutions of the existing house were identified through visual inspection and probing on walls and floors. For scenario N, only detailed drawings and lists of building quantities were necessary. Scenario R required information both of the original building and of the projects. Finally the flows of material and energy of each scenario/system were quantified and evaluated according to process analysis similar to life cycle analysis [5,19]. This final stage proved to be particularly difficult to carry out not only because of the scarce information on the embodied energy in building materials, specific to the local building context, but also because emissions are not directly proportional to energy (as they depend on the energetic mix on a given location and moment). Therefore, a certain degree of simplification had to be adopted.