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Embodied energy of conventional load-bearing walls versus natural stabilized earth blocks

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ABSTRACT

According to recent studies, the manufacturing and construction of the structural elements of buildings (for example, columns, beams and load-bearing walls) represent the largest proportion of embodied impacts. Some of these reports highlight the need to analyse the materials and techniques used today in order to make the building sector more sustainable. This paper presents the results of embodied energy and global warming potential, using life cycle assessment (LCA) methodology, for load-bearing walls, being these one of the most common types of structures for buildings. This study analyses through an eco-design tool new options for materials used in the construction of structural load-bearing walls. The research aims to examine the environmental performance of each material alternative assessed: fired clay brick masonry (FC), concrete block masonry (CB), reinforced concrete-based wall (RC), and stabilized soil block masonry (SS); stabilized with natural fibers and alginates. These conventional and new materials – especially those with a low level of embodied energy, such as earth blocks – are evaluated from the point of view of their environmental consequences.

1. Introduction

Sustainable construction is a response to the growing awareness of the negative impact of buildings on the environment. Designers (architects and engineers) have an important stake as the selection of materials and construction systems are now of great importance. Due to this significant impact of the construction sector on the environment [1], different measures are now being taken to assess construction activity from a strictly environmental perspective. According to some studies, around 20% of the total impacts are related to manufacturing, construction, demolition processes and final disposal of building materials, elements and systems [2]. Long operation periods, versatility, high structural complexity and material comprehensiveness mean that buildings are treated as intricate and unique objects in ecological studies [3]. Although recent years have seen vigorous scientific evaluation of the environmental impact associated with buildings, there is still a lack of standardized environmental analysis procedures that focus on construction technologies. In this sense, the application of the life cycle assessment (LCA) [4,5] helps to clarify the consequences for the environment of using certain building materials and elements such as composites, and LCA is now recognized as an important tool for the environmental assessment of solutions in the construction industry.

The proper selection of building materials is important for sustainable development, and there is a clear need to design and construct buildings in a way that supports the concept of sustainable development. What is more, the environmental impact of construction material not only depends on the material itself and the other elements used in building, but also on the way they are put into place, the maintenance requirements, the system of longevity and the distance from the purchasing point to the construction site, etc. This means that the selection of materials or building systems requires the exactness of the LCA.

Energy in buildings can be categorized in two types: the amount of energy required for the maintenance/servicing of a building during its useful life operating energy (OE) and the energy capital represented by the building materials used in the production of a building embodied energy (EE). A study of both these types of energy consumption is required for a complete understanding of building energy needs. A building's embodied energy can vary greatly depending on the choice of building materials and techniques. Reinforced concrete walls, fired clay brick masonry, concrete block masonry and beam and block slabs form part of the common conventional construction systems used in the main structure of buildings in Spain. Similar building systems can be found in many other developed and developing countries.

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Alternative building technologies such as stabilized soil blocks can minimize a building's embodied energy [6–12]. Generally, the materials used to construct the structure of a building represent more than 50% of its embodied energy [13]. In this sense, the use of alternative materials, such as mortar/concrete blocks, stabilized soil blocks or fly-ashes instead of materials with high embodied energy content, like reinforced concrete, could cut cumulative energy by 20% over a building's 50-year life cycle [14]. Recycling building materials [15,16] is also essential to reducing the embodied energy level in the building, for instance, the use of recycled steel and aluminium confers can mean savings of more than 50% in embodied energy [17].

Early studies from the 1960s and 1970s focused on the life cycle stages of certain products, and emphasised the analysis of the efficiency of energy consumption and its sources, the use of raw materials and, to a lesser extent, waste disposal. For decades, such studies applied LCA analysis to construction materials due to their high potential environmental impact, and this research is reflected in current literature on the subject. Energy requirements for the production and processing of different building materials, CO_2 emissions and the implications for the environment have been studied by Buchanan and Honey [18], Suzuki et al. [19], Oka et al. [20], Debnath et al. [21], Pargana et al. [22] and Praseeda et al. [23]. Some researchers have analysed the proportion of embodied energy in materials used, and carried out LCAs of existing conventional buildings [24,25]. Other approaches and simplifications have also been applied in LCAs for building materials [26], and there are numerous studies in which LCA is used to evaluate the impact of different construction materials and solutions [27–30].

2. Research aim and methods

Most part of the papers available in literature use LCA tool in case studies due to the need to fully define all the variables within the limits of the analysis [31–37]. In other cases, research is done by means of a LCA theoretical study through a literature review [22,38–41]. Moreover, other researchers limit the LCA applicable results to a specific climate area [42] or a specific regulatory environment [40]. And there are also models of analysis seeking to apply LCA tool to obtain improvements in the design of the processes of manufacturing and construction [43,44]. This study is not intended to reach the definition level of a given case study but to support designers' environmental concerns establishing a first approximation using the parallelism between structural parameters and LCA of different materials commonly used in load-bearing walls.

Industries that produce building material are considered to be among the largest fuel consumers in the economy, so savings in fuel consumption in this sector could have a substantial impact on an economy's total fuel demand [45]. Moreover, environmental assessments that include the energy used in the production of building materials are vital for extending the life cycle of the product. Environmental assessments of building material production can provide criteria for design decisions when choosing between materials that offer a similar performance for a given application [46]. In this regard, the energy consumption resulting from the manufacturing process of building materials is important in terms of LCA. Materials that require high production temperatures, such as concrete or ceramic, have a big negative impact compared to those whose production temperature is low or zero.

Our study takes an environmental perspective when comparing various conventional technologies for building walls to others that use new low-impact materials. By identifying and quantifying the materials used in the manufacturing processes and applying LCA methodology, we identify the environmental impact of each building alternative studied. Summing up, our study identifies the processes involved in each technology, quantifies their associated impact and compares their environmental performance.

The aim of this research is to compare the environmental aspects and potential impact associated with the construction, maintenance and disposal of walls in three-storey buildings, determining the option with the lowest negative impact in relation to mechanical and structural characteristics. A life cycle assessment was made of three models of housing blocks erected with load-bearing walls that varied according to their material structure. The options compared involved conventional and unconventional building materials, therefore, the study analysed:

- fired clay brick masonry (FC),
- concrete block masonry (CB),
- reinforced concrete-based wall (RC),
- stabilized soil block masonry (SS).

3. The conventional and unconventional materials used

All construction material is manufactured from a combination of raw materials that involve energy expenditure and associated waste. Therefore, the energy cost of manufacturing building materials is an essential element in computing environmental impact, and manufacture is probably the element most widely cited when considering the environmental impact of construction materials. This analysis raises typical questions such as: Are the raw materials renewable? Are they scarce? Are they important to the global environment? How much energy is required and how much waste is produced in the manufacture? What impact does this waste have on the environment?. The construction process also involves energy expenditure and produces waste, and also poses more important questions: How much manufactured material is used? Can materials that cause less environmental impact be deployed? How much energy is used? How much waste is produced? What is the environmental impact of the waste? Such questions can only be answered according to the specific structure to which they are applied. Increasing attention is now being given to the construction phase as part of efforts to make construction more sustainable.

To establish a comparative standard, we have chosen common, and not so common, building materials widely used for a specific building typology: Fired clay brick masonry (FC); concrete block masonry (CB), reinforced concrete-based wall (RC), and, the least common element, stabilized soil block masonry (SS). The features of the different construction systems are explained in the following sections.

3.1. Fired clay bricks

Bricks are made by shaping a plastic mass of clay and water which is later solidifies by drying and firing. Bricks are among the oldest and most enduring of mankind's building materials. They require a considerable amount of thermal energy during the firing process because they burn at temperatures of between 1000 and 1200 °C, depending on the clay type. Light-coloured clays usually require higher firing temperatures than dark-coloured ones. This thermal energy amounts to 3.75–4.75 MJ per brick [47]. We applied an average value of 4.25 MJ per brick (standard size in Spain: 240 mm × 115 mm × 70 mm) for the comparison and computation of the energy content of buildings and masonry.

3.2. Concrete blocks

Light-weight/low-density concrete blocks are commonly used in the construction of envelope walls in multi-storey buildings. They are also used to a lesser extent to build load-bearing masonry walls. The basic composition of the blocks is cement, sand and