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Repercussion the use phase in the life cycle assessment of structures in residential buildings using one-way slabs

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ABSTRACT

This study incorporates the use phase in the life cycle assessment (LCA) of reinforced concrete structures that are composed of one-way slabs. Sustainable construction is one of the main future objectives of the European Union; therefore, useful and reliable tools will be necessary for its implementation. The usefulness of the LCA for the selection of structural alternatives depends on the data quality. The Environmental Product Declarations collect the production phase of building materials, but it is necessary to incorporate the particularities in the implementation and use phases. This work proposes a stage that considers the use phase in the structural part that does not belong to the building envelope and provides a methodology that reflects the characteristics of each climate zone where it is applied. All of the representative variables to define the structure of a building are combined: column grids, variations in the geometry of one-way slabs, and different materials. A discrete model that incorporates 360 cases is constructed to compare the reliability of the model with a study on real structure projects. The results show the importance of the use phase in residential buildings with respect to the effects generated during the other phases (production, execution and demolition), as well as its high variations, up to 140.4%.

1. Introduction

At the turn of the XXI century, residential building has an uncertain future. By the end of the XX century, construction in general and edification in particular have been the economic engines of many industrialized countries, particularly ours (Bernardos Domínguez, 2009). The economic crisis, speculation, and effect caused by the real estate bubble led to a failure in the system. Subsistence is part of the differentiation, which must be based on: professionalism, quality, innovation, competitive prices, improvement of performances, and so on.

The crisis of the construction sector and the difficult economic situation lead to placing an added value on products, attempting to make them competitive in terms of the total costs, which are simultaneously sustainable. Sustainability is based on three interrelated basic aspects: environment, economy and society.

To include these new demands in the constructive processes, the Spanish Building Technical Code (Ministry of Housing Spain, 2009) (CTE, for its initials in Spanish) incorporated guidelines to increase the quality and sustainability of constructions, fostered innovation in the construction processes and established methodologies to control and improve energy efficiency. In reality, this regulatory framework is a document of minimums because it leaves an open possibility for the designer to contribute different solutions, as long as the performances are identical to or higher than the minimum performance that is established in the corresponding basic document. Similarly, the Spanish Instruction of Structural Concrete EHE-08 (Ministry of Public Works Spain, 2008) has in its Annex XIII a criterion to evaluate the contribution of structures to sustainability. Their application in the design of buildings indicates the consideration of aspects such as energy efficiency and the environmental effect. The aim is to adapt the buildings to the proposals of the European Union (EU) by 2020. Overall, this commitment is based on decreasing CO_2 emissions (Hong et al.,

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2012) by 20%, improving energy efficiency (Kim et al., 2013) by 20%, and increasing energy consumed from renewable sources to 20% (E. C. for Standardization, 2014a), (E. C. for Standardization, 2014b). This approach will lead to progress towards sustainable construction (Rincón et al., 2013), (Silvestre et al., 2014).

In Europe, 42% of the energy consumption and 35% of the greenhouse effect gases originate from buildings (Yu and Kim, 2014), (Vega et al., 2010). The current norm CTE-HE projects that buildings will reduce energy consumption during their useful life; the norm establishes thermal transmission limits of elements that compose the building envelope (Lartigue et al., 2013). It places no limitation on the intermediate floors.

In recent years, numerous studies examined the thermal behaviour, which mainly concerned the energy efficiency of the buildings; there are also some studies regarding the composition of facades (Del Coz Diaz et al., 2010), one-way slabs (Fernandez-Ceniceros et al., 2013), and specific elements, such as hollow blocks (Del Coz Diaz et al., 2011) (del Coz Díaz et al., 2009).

The worrisome increase of the burden to the environment has led to the use of instruments, such as the Life Cycle Assessment (LCA), to quantify the environmental damage caused by production, application of processes and/or service management (Elduque et al., 2014). The construction sector follows this trend; consequentially, much effort is currently devoted to developing studies based on LCA. These studies mainly focus on different fields: building materials (Kellenberger and Althaus, 2009) (Zabalza Bribian et al., 2011), building construction (Reddy and Jagadish, 2003) (López-Mesa et al., 2009), building use (Alvarez-Ude, 2003), building engineering (Ortiz et al., 2009), and demolition (Yu, 2013) (Blengini, 2009). Considering the global aspects of a building, the construction phase has lower energy consumption expenditures than the remainder of the useful life of the building (Menoufi et al., 2012). Buildings consume 20–50% of the natural resources depending on the environment in which they are built. Three phases can be established in the edification process: construction (materials, means of transportation, energy to build hours, etc.), useful life or use phase (energy and water consumption, maintenance, etc.), and demolition (wastes, transportation, recycling of material, etc.). Some researchers rate this type of expenditure as approximately 35% during construction, 60% during use and 5% during demolition (World Green Building Council,).

Research is focused on the assessment via the LCA of different structural alternatives, which are solved using plane frames and one-way slabs. This assessment is made considering the use phase and quantified its repercussion during the life cycle in a specific scenario. It is important to highlight that a proper assessment is affected by specific local aspects of each zone (Stazi et al., 2014). The level of technology, environmental issues, raw materials, customs, and so on significantly affect the assessment.

In the past, one-way slabs only had one-function, supporting loads, but over time, additional functions have become requirements, such as soundproofing, fire resistance and thermal insulation. Sustainable construction can be defined as being particularly devoted to respecting and committing to the environment; it involves the efficient use of energy, water, resources and non-pollutant materials; and it is healthier and directed to the reduction of environmental effects (Ramirez, 2002). The design of a structure is more valuable in terms of sustainability when: optimize material consumption, useful life is increased (producing a higher amortization of the effects of the execution phase) and has better contributions to security against fire, acoustic comfort and thermal behaviour during the use phase of the structure.

The tendency concerning the European rules, which were established by the European Committee of Normalization CEN/TC350, lead to the use of LCA tools, which are supported by the Environmental Product Declarations (EPD) (Fraile-Garcia et al., 2015). The LCA can be used as a variable for the selection of structural alternatives, which requires systematization and previous knowledge of the variables that are significant to the construction process. In this sector, it is important to highlight the local character of both the materials and methods (Fraile-Garcia et al., 2016). Using only databases without considering the field data can lead to misguided conceptions (Chau et al., 2015).

The product, which consists on structure of reinforced concrete using one-way slabs, requires the incorporation of impacts derived from the use phase. This structural typology presents an important geometric variability, which is incorporated into this study by analyzing a group of representative structures (different spans of slab and beams). The proposed scenario for the use phase is based in a deep analysis of the normative and statistical data of the region. This information includes parameters such as mix-energy used in heating and temperature gradients.

Getting an impact assessment in all phases of product lifespan allows better evaluating the different alternatives. Therefore, the object of this work is to assess and quantify the repercussion of the use phase on each specific functional unit (m^2 of structure in this case) for the different implemented structural solutions with one-way slabs, in order to generate information about the entire environmental effect of the implemented structure for its complete lifespan.

2. Methodology

The study the environmental effect of the full life cycle of different structural alternatives based on one-way slabs, will enable us to incorporate the environmental aspect in selecting the structural solution. It should identify the representative parameters.

To present an approximation to the current reality, a study analysed the real structures of residential building with more than 200,000 m^2. Based on real buildings that were constructed between 2005 and 2012 in the zones of *La Rioja* and *Álava* (Spain), this study certified some known data and adjusted the study approach to the existing reality of the residential building sector. That study has the following conclusions:

- The "column-index," which is the ratio between the number of columns and the floor surface of the structure, is considered to be particularly important. The distribution of columns in the real structures was analysed, which was previously defined as the column-index in this study. The result shows that 91.93% of the sample of real projects is 0.050–0.080 columns/m^2.
- The typologies that were used were divided into one-way slabs (93.51%) and bidirectional slabs (6.49%). For one-way slabs, there are three types of resistant elements: a lattice joist (24.32%), pretensioned joist (65.84%), and rib cast-in-place (9.84%). For the bidirectional typology, there are two cases: lightened slabs (94.33%) and solid slabs (5.67%).
- The most used material for the lightening elements is vibro-compressed concrete, and expanded polystyrene sporadically appears.
- For the slab geometry, the usual total structural thickness is 30 cm, with a predomination of 70 cm interaxes.

To determine a group of representative structures a discrete number of possibilities that allow one to address the problem, different beam lengths (4.5 and 6 m) and one-way slab lengths (4 and 6 m) were selected with respect to the dimensions of the building. The combination of these four values results in four scenarios of column arrangement with the following column-index:

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