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Sensitivity analysis of Life Cycle Assessment to select reinforced concrete structures with one-way slabs

J. Ferreiro-Cabello [a], E. Fraile-Garcia [a,*], E. Martinez-Camara [b], M. Perez-de-la-Parte [b]

[a] University of La Rioja, Department of Mechanical Engineering, Edmans Group, Spain
[b] University of La Rioja (Spain), Department of Mechanical Engineering, Integral Design Group, Spain

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ABSTRACT

Life Cycle Assessment (LCA) tools are often applied to the production stage of structural projects. This study aims to determine the sensitivity of the real environmental impact according to aspects related to decisions made during the execution stage. This stage includes factors that are beyond the control of the planner or designer: control over production (hourly yield, waste management), location of production facilities (transport of components to building location). The present study analyzes and evaluates three variables: distance travelled for component transport, working hours, and materials wasted during the production and construction process. Limit values are established according to six possible scenarios. Based on the results, it can be concluded that hourly yield had a minimal effect on the generated environmental impact. Transport and material waste, on the other hand, are the factors that brought about the greatest variations in environmental impact. For example, the components that are most sensitive to transport can decrease environmental impact by 65.66% or increase it by 18.24% depending on project location. And when considering material wasted during production and construction, the environmental impact varied from −9.77% to 9.78%.

1. Introduction

The evolution of new housing construction is manifested by the introduction and use of new materials and technologies that adapt building practices to the demands of society: functionality, safety, economy, comfort, sustainability, maintenance, etc.

Nowadays, governments are placing increasing importance on sustainability. This trend is illustrated by the objectives established for 2020 in the EU plan 20-20-20. According to this initiative, sustainability standards must be incorporated into construction processes and the corresponding materials. Sustainability is achieved by combining economic, environmental, and social benefits. One of the basic tools used to evaluate environmental impact is Life Cycle Assessment (LCA).

This tool is frequently employed to identify the environmental impacts of a product, service or process throughout its life cycle [1]. The ISO 14040 standard presents a framework and methodology to analyze and evaluate environmental effects throughout the entire life cycle of a product [2]. A range of types of environmental impacts can be evaluated by LCA: global warming, ozone depletion, eutrophication, acidification, toxicity for humans and ecosystems, depletion of natural resources, energy consumption, land and water use, among others. The LCA methodology is divided into four main stages: goal definition, inventory analysis, evaluation, analysis and improvement [3–7]. In the past, research has focused on materials, building components and combinations of building components.

One of the most commonly used materials in construction is concrete [8]. LCA has been used: to determine specific quantities of recycled aggregates [9,10], inputs from industrial residues [11–14] or even combinations of both [15] to be incorporated into concrete. Other possible combinations of different materials have also been examined with the aim of improving the thermal properties of concrete [16,17].

The LCA tool has been applied during the design phase to: highways [18–20], sidewalks [21], facades [22], sewage systems [23] and others.

LCA performance depends on the information it utilizes and the quality of that information, as well as: knowledge of the technology used [24,25], local data [26], and possible simplifications or similar approaches [27].

LCA is often used as a tool to select viable and environmentally-beneficial conditions and alternatives. Prior studies have utilized LCA to analyze scenarios, sensitivity analysis, and uncertainty in the field of construction (see Table 1).

* Corresponding author.
E-mail address: esteban.fraile@unirioja.es (E. Fraile-Garcia).

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Table 1
LCA of construction scenarios.

Authors	Field	Methodology
Bueno et al. [28]	Sensitivity analysis of the use of Life Cycle Impact Assessment methods: A case study on building materials	EDIP 97/2003, CML 2001, Impact 2002 +, ReCiPe
Bueno et al. [29]	Significance of mobility in the life-cycle assessment of buildings	IPCC
Dong and Ng.[30]	A life cycle assessment model for evaluating the environmental impacts of building construction in Hong Kong	ReCiPe
Anastasiou et al. [31]	Comparative life cycle assessment of concrete road pavements using industrial by-products as alternative materials	IPCC
Ferrández-García et al.[32]	A comparison of alternative solutions	Ecoinvent
Su et al. [33]	Life cycle inventory comparison of different building insulation materials and uncertainty analysis	BESLCI
Pargana et al. [34]	Comparative environmental life cycle assessment of thermal insulation materials of buildings	CML 2001
Cellura et al. [35]	Sensitivity analysis to quantify uncertainty in Life Cycle Assessment: The case study of an Italian tile	CML 2, Ecoindicator 95, EDIP/UMIP 97, IMPACT 2002+

When dealing with reinforced concrete structures, it is necessary to consider the specific materials and factors associated with their production. The application of LCA in these types of structures has focused on reducing CO_2 emissions [36,37], total energy expenditure [38,39] or the waste generated during the construction of said structures [40], and also on determining different alternative structural solutions or materials [41,42].

A structural element utilized frequently in recent years is the one-way slab (Fig. 1). A previous study applied LCA and incorporated the most commonplace material production parameters and practices in construction processes [43]. That study conducted an analysis of the environmental impact of different options for a selected building type, varying the column layout, geometry and types of materials employed.

The present study deals with the sensitivity analysis of LCA to select reinforced concrete structures with one-way slabs, aiming to determine the sensitivity of the real environmental impact according to aspects related to decisions made during the execution stage. This stage includes factors that are beyond the control of the planner or designer: control over production (hourly yield, waste management), location of production facilities (transport of components to building location).

Three variables are analyzed and evaluated: distance travelled for component transport, working hours, and materials wasted during the production and construction process. Six alternative scenarios are proposed for the sensitivity analysis of the environmental impact of the different structural solutions. Each structural solution includes different distances for transporting components to the building site, more or less on-site staff work hours, and greater or lesser quantities of materials wasted during construction. The objective is to identify the effects of the different scenarios in search of a structural solution that minimizes the environmental impact of a building.

2. Methodology

To conduct the sensitivity analysis herein, a prior study was considered as the base case [43]. In the base case, one-way slabs are analyzed while the building's column layouts for the principal beams and the slab configurations are varied. These structural solutions combine different slabs and reinforced concrete beams to offer a wide range of alternatives. Thus, to conduct this study, a specific number of cases were proposed to encompass the most representative alternatives from the range of possible solutions.

The prototype building considered to calculate the structural solutions for the base case and all the proposed alternatives has the following dimensions: 18 m × 12 m. The column layout in the building includes two values of length for both beams and one-way slabs, providing four examples of the aforementioned infinite range. These cases are within the usual values for reinforced concrete structures: beams of 4.5 and 6 m (short beams SB, and long beams LB) and one-way slabs of 4 and 6 m (short slabs SS, and long slabs LS). The column dimensions are 30 × 30 cm and the thickness of the total slab is 25, 30 or 35 cm. Beams of different widths are used: this variable starts at 30 cm and increases up 90 cm. The interaxis considered for the one-way slab has a fixed value of 70 cm [43].

Thus, the different structural solutions proposed can be divided into the following groups:

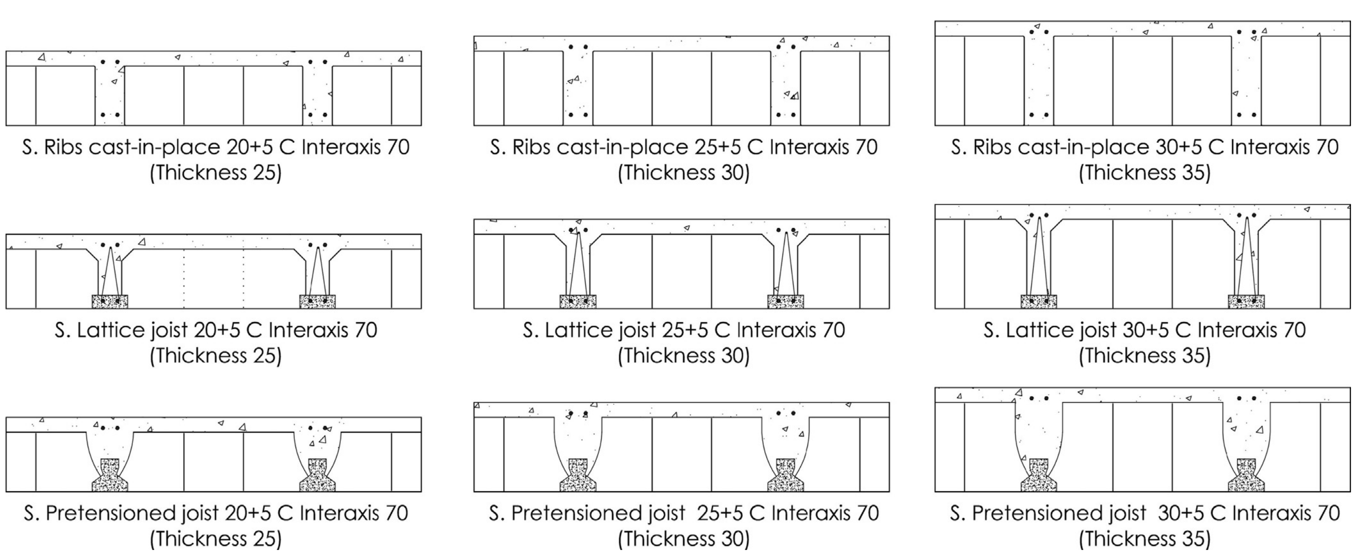

Fig. 1. Typologies of one-way slab.