# BIM-based LCA assessment of seismic strengthening solutions for reinforced concrete precast buildings

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**Abstract.** The socioeconomic importance of the construction sector contrasts with its high environmental impact due to the intensive consumption of natural and energy resources throughout the useful life of the buildings. Thus, this sector has been the object of actions that promote a low-carbon construction, given its potential to reduce emissions of greenhouse gases by the construction and rehabilitation with more sustainable materials and techniques. With the development of the Building Information Modeling (BIM) methodology, it is possible to develop the different projects in an integrated and collaborative platform since its initial phase, also facilitating the integration of life cycle assessment (LCA). The present work aims to evaluate and compare the environmental impacts of prefabricated concrete elements of new construction and solutions of seismic reinforcement of these elements in an existing building, as well as, their costs, through LCA methodology and Life Cycle Cost (LCC). In order to perform the LCA, in a cradle-to-grave approach, the BIM-LCA methodology was used, using specific software. For this purpose, the structural BIM model of an industrial building with prefabricated concrete structure was developed and its LCA was done. It was considered the model of a similar building with 30 years of existence, in whose structural calculation was not considered the correct strengthening to face seismic actions. The respective seismic reinforcement solution was analyzed and the corresponding LCA was accomplished. For each case, the LCC was calculated.

The analysis of the two buildings allowed to conclude that an LCA based on the BIM methodology leads the project team to easily perform different simulations of more sustainable construction solutions and to automatically extract the necessary data for the various analyzes that they wish to achieve. It also highlighted the importance of rehabilitation in the construction sector, since the environmental impacts and the associated costs are reduced when compared to the construction of a new building.

**Keywords:** Life cycle assessment; Life cycle cost; Sustainable construction; Precast elements; Seismic strengthening; BIM; Revit; Tally.

# 1 Introduction

The construction sector is one of the most harmful to the environment as it produces waste and consumes a high amount of energy and natural resources. Only in the European Union, it is estimated that the construction industry accounts for 50% of raw material consumption, 36% of carbon dioxide emissions and 40% of energy consumption (Commission European, 2017; Santos et al., 2019). Consequently, it is important to adopt strategies to reduce energy consumption, greenhouse gas emissions and the environmental impacts caused by building materials and processes (Antón and Díaz, 2014). For the success of these measures, it is crucial to effectively coordinate all the resources allocated to the project from the extraction of raw materials until building demolition. However, these diligences are not focused only for new construction. In the sequence of current events (e.g. natural disasters), the existent buildings may present some functional and structural anomalies, so, several buildings need to be retrofited in order to assure safety and extend their service life. This action contributes to preserve the built elements and to reduce the amount of building demolitions.
Thus, this paper applies the LCA methodology in cooperation with BIM methodology in two case studies: the first one refers to the construction and demolition (at the end of service life) of precast elements of a new building and the second refers to seismic reinforcement of a similar existent precast structure and its demolition. Furthermore, the LCC is also calculated in both situations to support decision making.
The object of study is an industrial building located in the center of mainland Portugal and, resourcing BIM methodology the parametric buildings` model (structural) was developed in Autodesk Revit, in which was introduced the required data to evaluate the environmental performance of materials and construction processes, throughout their life cycle.
The main objectives are (1) determine, among the mentioned alternatives, the option with the lowest environmental impact and the lowest associated costs, and (2) to evaluate the integration of LCA in the BIM model. In order to contribute to sustainability, it is intended to understand which option is more suitable, refurbishment with seismic reinforcement or build a new building.

# 2 Case study

## 2.1 Building characterization

The building under study is a single-story industrial building, located in the center of Portugal. It has a total gross building area of 34 614.42 $m^2$ and consists in a structure with 189 beams, 131 columns and 144 panels, in reinforced and prestressed concrete. All the beams in the structure are connected with the columns by A500 steel rods or class 8.8 threaded rods that emerge from the interior of columns, and the structural design of the new industrial building includes the seismic requirements of the current design standards.

It was considered an existing industrial building with the same geometric configuration, so, the gross area and the number of precast elements are equal, however, based on the analysis of 16 industrial design projects before the 90's, it was observed that the amount of steel and the section of the columns are smaller. In addition, it was considered that there are not mechanical connections between beams and columns, considering a non-seismic structural design, which increases the risk of structural damage under an earthquake. Therefore, to ensure efficient seismic performance, this building needs to be strengthened. For the development of the 3D BIM model the plans, elevations and sections of the industrial building in digital format Autocad were used. Figure 1 and 2 represent, respectively, the new industrial building and the existing industrial building model in the 3D view, which was developed using Autodesk Revit.

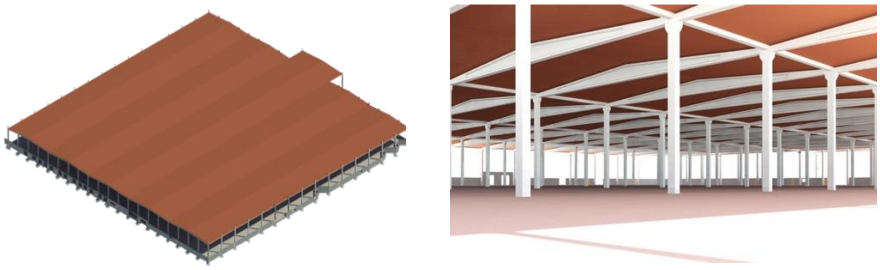


**Fig. 1**-3D view of the new industrial building

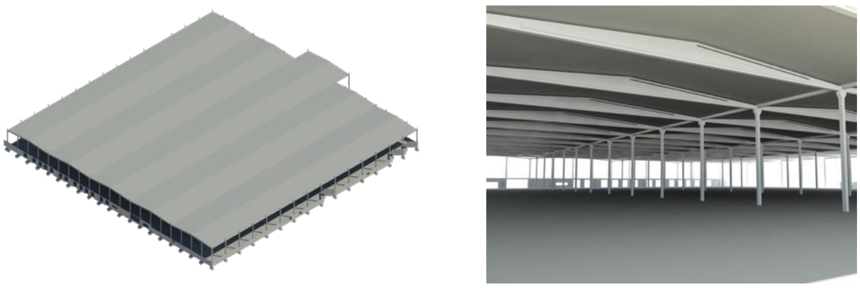


**Fig. 2**-3D view of the existing industrial building

## 2.2 Methodology

The first stage of the study was focused on the buildings' modelling applying the BIM methodology. This was followed by the second stage, that performed the assessment of the LCA, in which was defined the goal and scope, the inventory and the environmental impact assessment of each case. In the third stage, the LCC were calculated, where the construction and demolition costs of the new building and the costs of seismic reinforcement and demolition of the existing building were calculated. In the last phase, the discussion of results is presented.

## 2.3 Life Cycle Assessment

As mentioned in ISO 14040 and ISO 14044 standards (ISO 14040, 2006; ISO 14044, 2006), Life Cycle Assessment is developed in 4 phases: i) Goal and Scope definition; ii) Inventory; iii) Impact analysis and iv) Interpretation.

In the first phase the objectives, the functional equivalent, the boundary conditions and the limitations are defined. The main objective of this paper is to understand which of the two alternatives has the least environmental impact. For this, the impacts inherent of construction, implementation and demolition of the prefabricated elements of the new industrial building are compared to the environmental impacts of the insertion of the seismic reinforcement and demolition of prefabricated elements in a existing building. The functional equivalent of the present case study will be $1m^2$ of built area. For boundary conditions, was considered European standards and software limitations. The BIM-based software Tally (a Revit plugin for LCA) does a cradle-to-grave analysis, being also the approach used in this study.

The inventory corresponds to the phase where, among other aspects, the amount of raw material and waste produced during the building's life cycle are quantified. This can be done automatically by Tally or manually. For impact analysis, the environmental impacts are calculated using the TRACI method which is the Tool for the Reduction and Assessment of Chemical and other Environmental Impacts developed by the U.S. Environmental Protection Agency (EPA, 2012), following the standards ISO 14040 and 14044 (ISO, 2006; ISO 14040, 2006). The impact categories considered in this study are: Global warming (kg $CO_2$ eq), Ozone depletion (kg CFC eq), Acidification (kg $SO_2$ eq), Eutrophication (kg NOx eq) and Smog formation (kg $O_3$ eq). Although EN 15804 standard (BSI EN 15804, 2014) and other works use other impact categories, in this work, these five impact categories were selected since they represent the most harmful environmental impacts, a reason why they are often assessed in LCA. Beyond that, those are the impact categories calculated by Tally. Interpretation is considered by many authors to be the most important phase because it examines the results obtained from the inventory and environmental impact assessment (Mateus, 2009). As a consequence, this phase will be presented in section 3.

## 2.4 Life Cycle Cost

The LCC consists on the sum of the costs estimated from conception to the final disposal of a product. This method, based on existing options, allows selecting the most efficient and economical alternative (Schade, 2007). Thus, to calculate the LCC, the costs of the construction and demolition phase of the new building were accounted for a lifetime of 50 years and the cost of seismic reinforcement and demolition of the precast elements of the existing building were accounted for a lifetime of 20 years (considering that the existent building is 30 years old). Although most LCC models use Net Present Value, this cannot be applied when the alternatives to be compared have different service lifes (Schade, 2007) and as there is not enough data to apply other methods, only the budget for the construction, refurbishment and demolition of the buildings will be presented. This calculation includes material, equipment and workforce costs.

# 3 Discussion

## 3.1 LCA of the new building

After the building modelling, the materials were defined according with Tally's database, always trying to choose those ones that have more similar characteristics to the real ones. The distance from the factory to the construction site was defined (638 km) and finally the quantities of materials were automatically extracted from the BIM model to the LCA calculation software (Table 1).

**Table 1-** Quantity of materials obtained in BIM 3D model for the new industrial building

| Structural element and equivalent functional | Quantities (Tally) |
| --- | --- |
| **Steel cable in beams (kg)** | 59 874.40 |
| **Steel rod in columns (kg)** | 164 800.70 |
| **Welded mesh in panels (kg)** | 10 002.00 |
| **Precast concrete in beams ($m^3$)** | 676.45 |
| **Precast concrete in columns ($m^3$)** | 1 565.00 |
| **Precast concrete in panels ($m^3$)** | 526.31 |

Tally calculates the environmental impacts per $m^2$ of built area for each phase of the life cycle. It was found that the category with the highest contribution is global warming and the phases with the highest impact are the production, the construction and the final disposal (Figure 3).

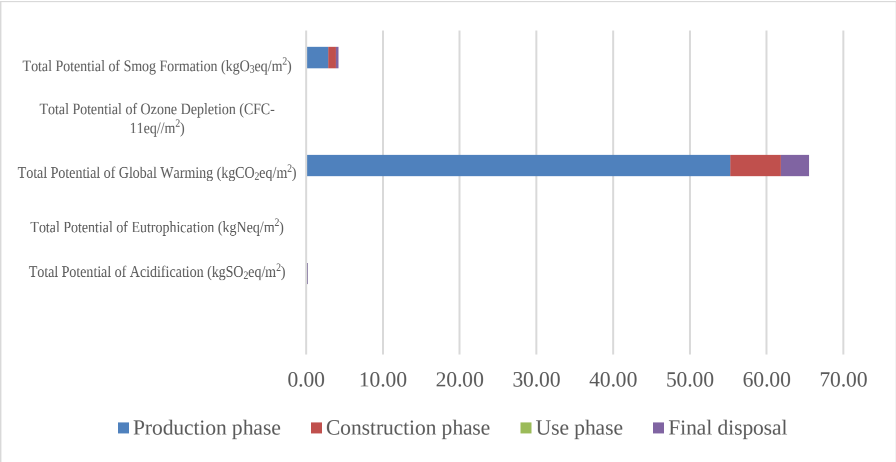
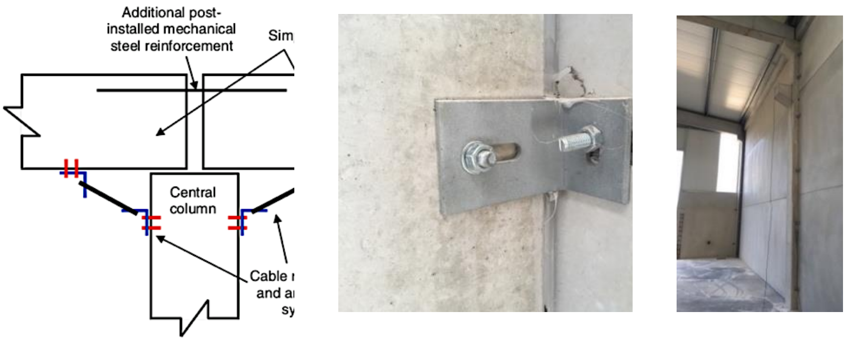



**Fig. 3 -** Environmental impacts per m2 of the built area during the life cycle of the new building

### 3.2 LCA of the existing building

After a literature review based on the typical failures of this type of construction, the seismic reinforcement solution depicted in Figure 4 was adopted (Bournas, Negro and Taucer, 2014), where it is possible to notice three types of steel connections: beam-beam connection, beam-column connection and panel-column connection.




(1) (2)

**Fig. 4** - (1) adopted seismic reinforcement solution and (2) panel-column connection

Thereby, the materials were defined according with Tally database and the distance between the construction site and the factory (100 km) was introduced in the tool. In this case, the steel quantities were not provided, so, the diameter of the rods was obtained based on real projects (Arrigoni et al., 2018; Bui et al., 2019). The length and additional measurements were calculated considering the CYPE database (Cype, 2019) and the *Orçamentos e Orçamentação na Construção Civil* (OOCC, 2019) (Cype, 2019) library and the dimensions of the building. One of the advantages of Tally is that it allows the entry of a certain amount of materials without necessarily model it. Thus, in contrast with the new building, in which the type of materials was provided by the manufactured, in this case, these data were estimated based on CYPE and OOCC library and then inputted into the model according Table 2.

**Table 2 -** Quantities of materials calculated and obtained for the existing industrial building

| Typology | Material | Quantity calculated (Excel) | Quantity obtained (Tally) | Difference |
|---|---|---|---|---|
| **Beam-beam connection** | Steel rod (kg) | 653.19 | 669.07 | 2.37% |
| | Grout (kg) | 115.585 | 116.5 | 0.79% |
| **Beam-column connection** | Steel rod (kg) | 1504.23 | 1551.86 | 3.07% |
| | Fastening element (kg) | 820.00 | 823.24 | 0.39% |
| **Panel-column connection** | Fastening element (kg) | 628.8 | 631.94 | 0.50% |

As Tally calculates the environmental impacts per $m^2$ of built area for each phase of the life cycle it was found that the impact category with the highest contribution is global warming and the phase with the large impact is the production (Figure 5).

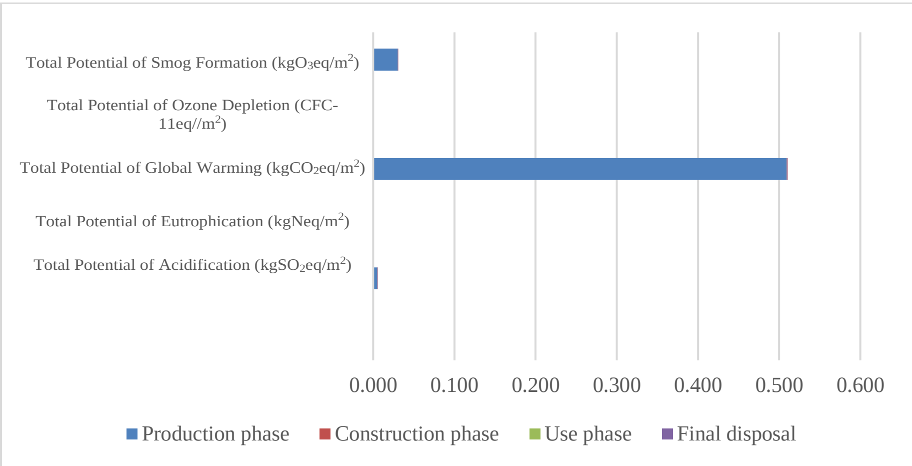



**Fig. 5 -** Environmental impacts per m2 of the built area through the life cycle of the existing building

For the demolition of the buildings, as both have similar dimensions, it was considered that the results would be equal, however, Tally does not account the impacts generated when the building is demolished. This tool only indicates the amount of waste that will be recycled, where it can be seen that more than 50% of construction waste can be recycled. Finally, the percentage of emissions in the construction of precast elements of a new building and the percentage of emissions generated in the implementation of seismic reinforcement of an existing building were calculated. Figure 6 depicts that for global warming the value obtained for the new building is 128.5 times higher than in the existing building. For smog formation, this value is 138.5 times higher than in the existing building. This difference is associated with the amount of material that is used in the production of precast elements of a new building and the amount used in the production of seismic reinforcement of an existing building. Thus, the alternative with the lowest environmental impact is the refurbishment of the existing building.

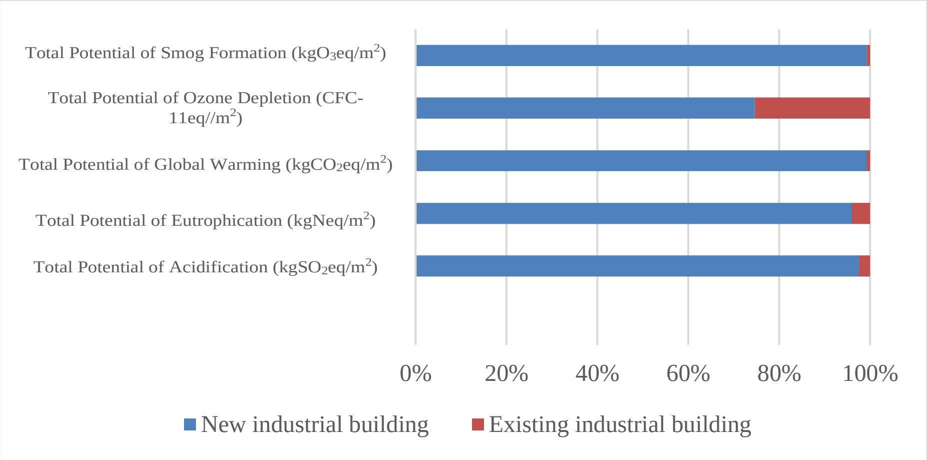



**Fig. 6 -** LCA Comparison between the new and the existing building

### 3.3 LCC of the new building

The costs of construction and demolition of precast elements were calculated, and all the amounts include material, workforce and equipment costs.

**Manufacturing costs of precast elements**

With CYPE, the total execution cost (manufacturing, transport and assembly) of the columns, beams and panels was calculated, accounting a total cost of 901 412.04 € (Table 3).

**Table 3 -** Construction total cost of the precast elements of the new building

| Element | Total cost (€) |
|---|---|
| Column | 170 458.25 € |
| Beam | 505 473.79 € |
| Panel | 225 480.00 € |

| | |
|---|---|
| Total | 901 412.04 € |

**Demolition costs of precast elements**

To calculate the demolition costs CYPE was also used. However, when comparing the amount of waste obtained from CYPE and Tally, the values were adjusted to only calculate the demolition of the precast elements (Table 4).

**Table 4 -** Total cost of demolition of precast elements of new building

| | |
|---|---|
| Total cost (€) | 205 083.88 € |
| Price per $m^2$ | 5.92 € |

Therefore, considering the execution and demolition costs of precast elements in the new building these accounts 1 106 495.92 €.

## 3.4 LCC of the existing building

The costs of the connection's seismic reinforcement and of the precast element's demolition were calculated. All amounts include material, workforce and equipment costs. Thus, taking into account the total cost of refurbishment with seismic reinforcement and demolition of precast elements in the existing building these accounts 291 751.46 € (Table 5).

**Table 5**-Total cost of seismic reinforcement and demolition of precast elements in the existing building.

| Element | Total cost (€) |
|---|---|
| Conection beam-beam | 59 003.65 € |
| Conection beam-column | 18 338.71 € |
| Conection panel-beam | 9 325.21 € |
| Demolition | 205 083.88 € |
| Total | 291 751.46 € |

Therefore, when comparing the costs of the new and the existing building, the costs of this one are 3.79 times lower than the costs of the new building (Figure 7).

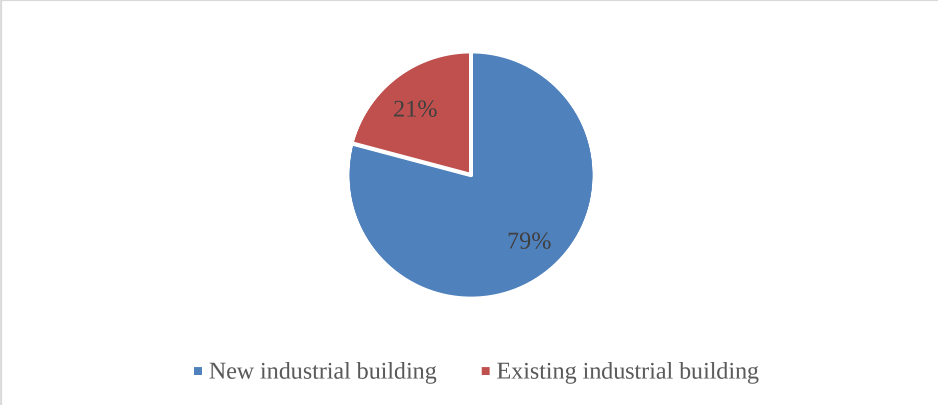



**Fig. 7 -Comparison between LCC of new and existing building**

## 4 Concluding Remarks

This article aims to analyze the costs and the environmental impacts associated with seismic reinforcement and demolition of precast elements of an existing building and to compare them with the costs and environmental impacts of the construction and demolition of precast elements of a new construction with similar characteristics using the cooperation between BIM and LCA.

Relatively to Life Cycle Assessment, this study was conditionate by the lack of materials in the Tally database. In addition, the tool does not calculate the environmental impacts when the new and existing building are demolished. If the values of the environmental impacts of the demolition of the new and the existing building were considered, the total environmental impacts would be higher than the results presented.

For the Life Cycle Cost, uncertainties were found between the costs of execution and demolition of precast elements and the seismic reinforcement costs, relatively to the real costs of each case. Indeed, in the case of demolition, how it is accomplished in different lifetimes, the inflation rate was not accounted because there are not projections for such a long useful life (50 years). Nevertheless, there is insufficient data to apply other economic indicators.

From the LCA and LCC analysis it can be concluded that the most advantageous alternative is the refurbishment of the existing building, because the environmental impacts are significantly reduced (the rehabilitation of the building saves up to 128.5 times the amount of CO2 emissions) and the costs are 3.79 times lower than the costs of the new construction. In addition, the seismic reinforcement allows the recovery of the building functional performance and ensures higher durability with the safety of the structural elements.

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