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Effect of dimensions on embodied environmental impact of buildings

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Abstract

Designers are faced with many options on material and technical solutions during the design phase of the building. Different studies proposing solutions and guidelines are presented in the literature. They help to guide the building project toward low CO_2-eq solutions. Despite all these studies, the influence of building dimensions on embodied environmental impacts hasn't been treated. The dimensions are the first parameters to be defined in the early design phase and can have significant influence in building's impacts. In this study, we aim to introduce the relationship between the dimensions of the building and their influence in its embodied environmental impacts. Here we limit our study in the case of buildings with structure in cementitious materials, to derive some general principles for design. To do so first, we have assessed the environmental impacts of a single room by progressing its span. Secondly, the impacts have been assessed by multiplying the room in length, width and then in height, by transforming it into a building. Thirdly, we addressed the problem of defining optimal dimensions of a building and construction from an environmental point of view. Finally, the environmental impacts of two different structures, reinforced concrete beam-columns and shear-walls have been compared. According to the type of construction considered, earthquake forces and dimensions in plan and height the study identified the progression of the environmental impacts and the definition of optimal dimensions of the buildings. A good definition of dimensions can reduce significantly the embodied impacts of the buildings. However, further work is necessary for better identifying the optimal dimensions of building by adding to this work the impacts of operation phase.

Introduction

The necessity of minimising the environmental impacts of buildings it is widely acknowledged, as they are highlighted as responsible for 33 percent of greenhouse gases emissions as well as for 40 percent of the primary energy used [1]. During the last 20 years, Life Cycle Assessment (LCA) method has been applied in several studies with a focus on the assessment of the environmental impacts of buildings and its materials, components or systems. The objective of such research efforts was the identification of building' elements, components or systems having the biggest impacts to the environmental impacts [2-4]. Other studies focused their efforts on the improvement of elements or components for the minimization of impacts of the operation phase [5, 6].

Moreover, further work has been focused in the identification of influence that design parameters such as lifetime, thermal inertia, thermal transmittance, shading system, etc, in for developing low impact projects [7, 8]. Even though, the building shape have significant influence in the environmental impacts previous works have been focused only on the identification that this parameter has to the energy efficiency of the buildings [9, 10]. Yet it appears that few work has addressed the buildings dimensions related impacts and their structural principle. Motivated by this gap, in this study we aim to identify the effect of building's dimensions on its embodied environmental impacts.

Method

The effects of dimension on embodied environmental impact of buildings are calculated by integrating the dimension of a "small room" (Fig. 1), for residential destination with a supposed lifetime of 50 years. First, the stratigraphy of the external walls, slabs and roof have been chosen among 42 different scenarios developed by the combinations of different insulation, wall elements and coverings. The thermal proprieties of wall, slab and roof elements are kept equivalent for covering the same functional unit. According to France regulations RT-2012 [11], the thermal transmittance of slabs should be greater than 3 m² K / W and for the roof greater than 4.5 m² K / W. Then, the environmental impacts of all stratigraphies are assessed with the help of Environmental Product Declarations (EPD) from the French national database INIES [12]. The stratigraphy presenting the lower CO_2-eq emission have been considered as supposed to be the most pertinent for our study. This choice was motivated by the reason that the low CO_2-eq stratigraphy is the most disadvantageous to the results of this study, because the effect of the dimensions is supposed to be lower in this cases. We have made this choice for calculating the minimal significant effects that the dimensions will have in the impacts.

The structural elements are pre-dimensioned according to Eurocodes norms [13, 14]. Since the seismic map separate France in five different zones [15], and the zones 1 to 3 cover almost 90% of the territory we have considered for the study only the seismic loads of zone 3 that cover also the other two. Consequently, of the loads considered in the calculation of the structure, the results of this study are not representative for the other 2 seismic zones (4 and 5) of France with higher seismic risk. An average ductility of the structure is considered and the earth of category C for considering earthquake loads via design spectrum according to Eurocode 8 [16]. In the end, the verifications of the structure for all load combination are carried out by modelling the projects scenario in ETABS software [17].

A step by step progression is applied to the dimensions of the room. The span of the beam, slab and roof have been firstly variated between 2 to 10 m. The influence of the variation of the span between columns and consequently the span of beams, slab and roof to the impacts has been firstly calculated. Then the room for different spans has been multiplied X, Y and Z dimensions for the calculation of the effects of dimension in plan and height. For the multiplications in X, Y and Z dimension, we have considered that each room will have an internal door and a window if it faces the external façade of the building.

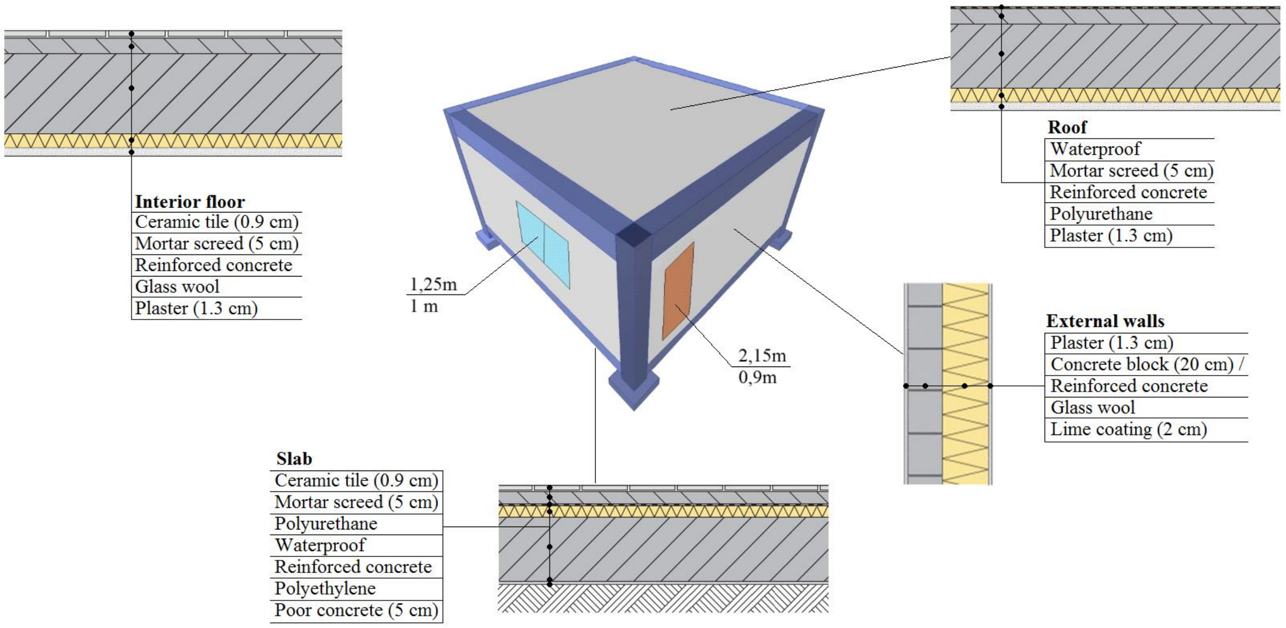

Figure 1: Details of the building and its elements.

The areas of the kitchen, toilets, and corridors are not considered in the process of the multiplication of the room in three dimensions. This progression’s process transforms the room into a single house and then in a multi-residential building, (the dimension of the structures created can be compared with this building’s type). The progression of dimensions of the room are applied in two different structure. One structure is composed of reinforced concrete beam-columns and the other of reinforced concrete shear-wall. In the end, the environmental impacts of two structures types are compared.

The assessment of the environmental performance of the building scenarios are undertaken according to the European standard [18]. As for the walls, slabs and roof the information of the EPDs available at INIES database are used for the assessment of the impacts of the whole scenarios. The impact categories of EPDs follow one of the NF P 01-010 standards [19]. The standard uses some impact categories from the CML 2001 method [20]. In this study, we have considered only the global warming potential (GWP) indicator but further information for other indicators can be found in Hoxha, (2015) [21]. Within the boundary of the assessment are considered only the materials and elements used for the construction of the building without considering the impacts of operation phase, since the aim of the study is the calculation of the effects of dimension only in embodied impacts of the building. This limit of the boundary, cannot affect the results because other studies have demonstrated that dimensions reduce the impact of operation phase.

Results

The environmental impacts of the building’s elements assessed for different spans are presented in Fig. 2. The environmental impacts of different elements vary differently when the span increases. Such elements are reinforced concrete shear-walls, walls in concrete blocks, columns, and foundations decrease their impacts when the span is increased from 2 m to 10 m. In the other hand, impacts of the roof decrease when the span is increased, due to the reason of the increment of the roof thickness for large spans. The impacts of the slab are always constant because the impacts of these elements increase with the span, but are in disproportion with the area of the building and consequently with unit considered for the assessment of the impacts in this study. In the end, impacts of beams present a minimum for an intermediate value of the span, which demonstrates the potential of the presence of a possible optimum of the span for GWP indicator of the building.

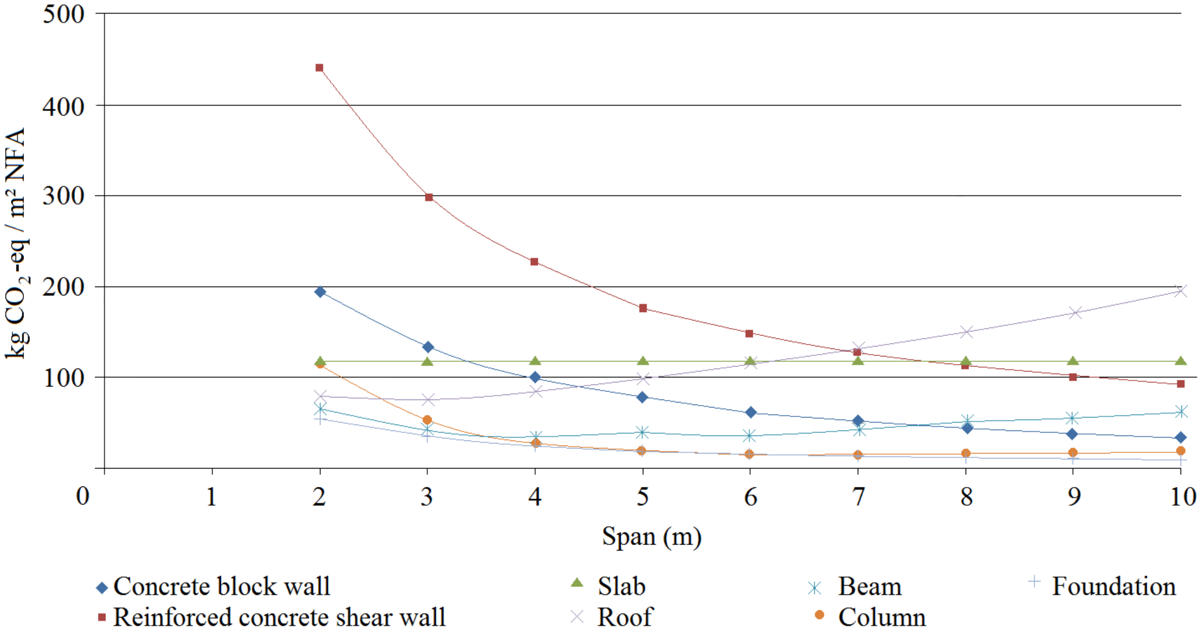

Figure 2: Effect of span in CO_2-eq gases of different building' elements.

For better understanding, the influence of the span in the GWP indicator, Fig. 3 presents the overall impacts of the room for different spans. The results are presented for two types of structures. The structure in reinforced concrete beam-columns (B-C) present a minimum for a span of 5 m and the structure in reinforced concrete shear-wall (SH-W) a minimum for a span of 7 m. In addition, the results of Fig. 3 demonstrate that the B-C structure present lower environmental impact than the SH-W structure for the span between 2-8 m, but not for bigger spans. These results are valid in the case of a simple room, but for better understanding the stability of this conclusion and for calculating the effect of the dimension in plan in embodied impacts, we have multiplied the room in X and Y direction.

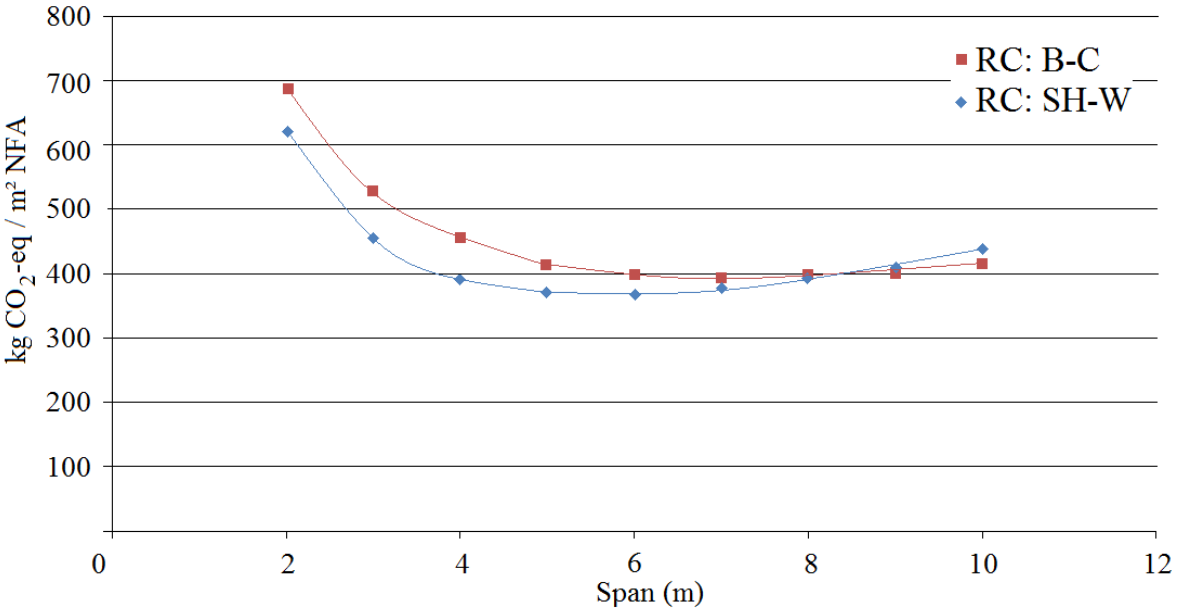

Figure 3: Effect of span in CO_2-eq gases of reinforced concrete beam-column (RC: B-C) and shear-wall (RC: SH-W).

For the B-C structure, the results obtained are presented in Fig. 4. The variation of building dimensions in plan, respectively in direction X and Y reduce significantly (around 20% for a span of 5 m) the overall impacts. It is important to be underlined that the reduction of the impacts can seem as significative only up to 25 m at X and Y direction. For more than 25 m, we remark only small reduction of impacts that can be presented as unsignificative. The results highlight the building with span of a 5 m as the best solution with lower impacts. Another remark of the results is that the earthquake loads have not influence in the CO_2-eq gases when the dimension of the buildings in the plan is increased.

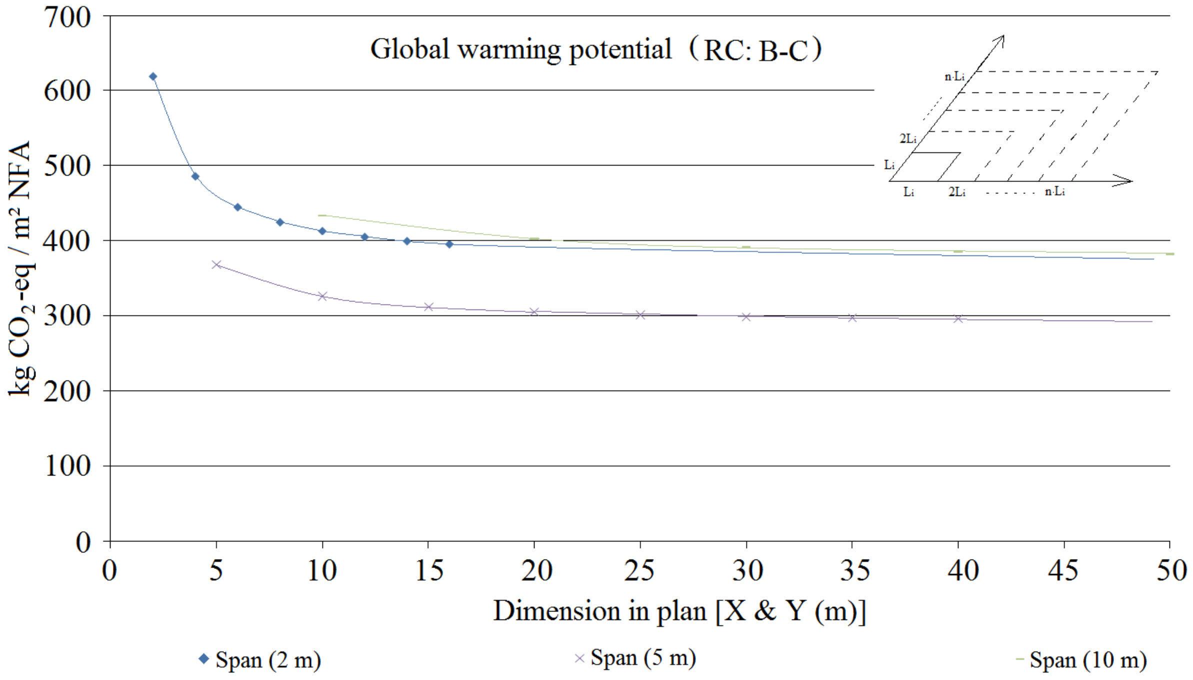

Figure 4: Effect of X & Y dimension in CO_2-eq gases of reinforced concrete beam-column structure.

In the case of SH-W structure (Fig. 5), the results are almost the same as those of the B-C structure. The only difference is for a span of 10 m for which the impacts are lower than for span of 2 m, while in the B-C structure the impacts for both spans 2 m and 10 m are similar. Another remark is that the structure B-C represents lower impacts than the SH-W structure for 1 level building. As for B-C structure, the span of 5 m presents the lower impacts compared to the impacts of a scenario where other values of spans are considered.

For this reason, the influence of the dimension in height of the building to its environmental impacts are calculated only for the span of 5 m. Finally, the influence of dimension at height of the building to the embodied impacts is identified by multiplying the room in Z-direction. The variations of the CO_2-eq gases of the building in function of the levels are presented in Fig. 6. In this case, the earthquake loads had significative influence on the impacts of the B-C structure elements and no influence on the impacts of the SH-W structure. The B-C structure, in the case of the negligence of the earthquake loads that corresponds to the zone 1 of the seismic map of France, presents the lower impacts whatever the number of levels. When the earthquake loads of the zone 3 are considered the B-C structure present and optimum for 5 level or 15 m of height of the building. Even for 6 levels the CO_2-eq gases are remained small and almost equal to those for 5 level, but for up to 6 levels the impacts are significantly increased. Based on the results of Fig. 6, when the building is constructed in a moderate seismic zone, we can conclude that the reinforce concrete beam-columns structure presents lower impacts for dimension in plan 25 x 25m and height of 15 m.

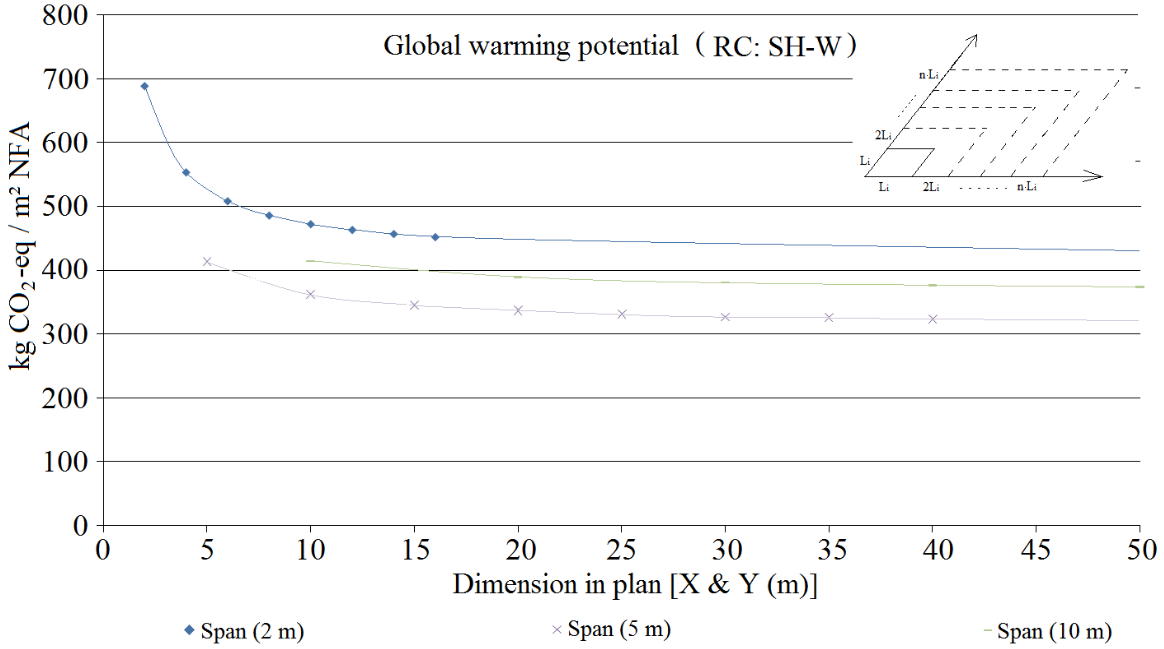

Figure 5: Effect of X & Y dimension in CO_2-eq gases of reinforced concrete shear-wall column.

For the SH-W structure, the earthquake doesn’t influence the impacts of the building. For this structure, the minimum is presented at 16 level or 48 m of height. Based on results we can conclude that the reinforced concrete shear-wall structure present lower impacts in the cases of a building situated in moderated seismic zone when tall buildings are planned to be build. In the case of the small building with the height lower than 15 m, the B-C structure is recommended, in both moderate and non-moderate seismic zone as they presented always lower impacts.

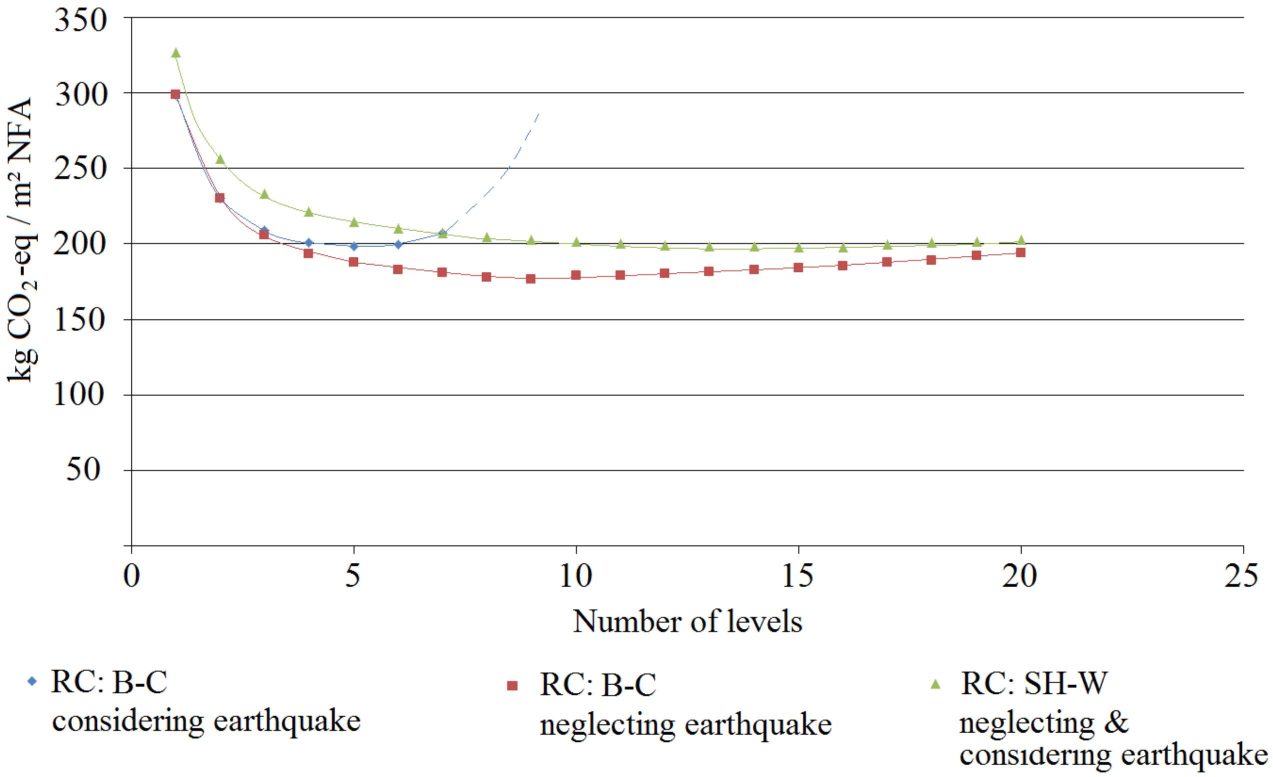

Figure 6: Effect of Z dimension in CO_2-eq gases of reinforced concrete beam-column (RC: B-C) and shear-wall (RC: SH-W).

In the end, Fig. 7 summarised the effect of dimensions on embodied environmental impacts of the building. The comparison of impacts of the single room with those of the building in plan and of the building in height, highlight the conclusion that a good definition of the dimension of the building can decrease drastically its impact, with around 50 %. This conclusion is almost the same for both structure types.

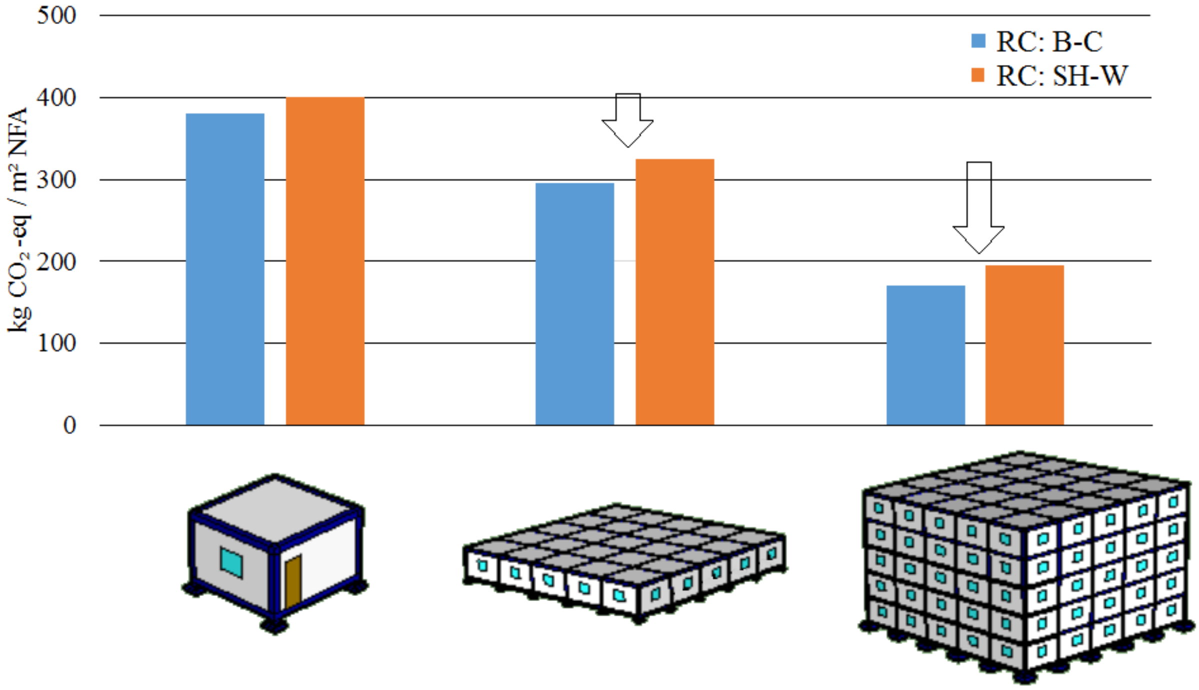

Figure 7: Effect of dimensions on embodied environmental impacts of building for reinforced concrete beam-column (RC: B-C) and shear-wall (RC: SH-W).

Conclusion

The dimensions have a significant influence to the embodied environmental impacts of the building. In this study, we show that a good definition of the dimension can reduce by 50% the CO_2-eq gases of a building. The Z-dimension have a bigger influence in the reduction of CO_2-eq gases than X and Y dimensions. These conclusions are valid for both, a reinforced concrete beam-column structure and shear-wall structure. The beam-column structure shows lower impacts than shear-wall structure when the building is situated in a non-seismic zone. Even in a moderate seismic zone, beam-column structure shows to be more CO_2-eq friendly than shear-wall structure, when the height is lower than 15 m. Only in the case of a building' height up to 16 m situated in a moderate seismic zone, the reinforced concrete shear-wall structure is recommended to be employed as more CO_2-eq friendly.
Since the building's dimensions show to positively influence the reduction of CO_2-eq gases, the construction of dwellings must be more advantageous than single-houses. The conclusions of this work are mostly directed to architects, which must consider the advantage of dimensions for reducing the impacts of building at the early design phase.
Further developments are necessary for better identifying the effect of the dimensions in embodied of buildings with T, U I, etc, shape. Furthermore, a better definition of the optimal dimensions of buildings would request in addition to this work the impacts of operation phase.

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