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# Construction waste estimation depending on urban planning options in the design stage of residential buildings

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## HIGHLIGHTS

- This study compares the environmental impact of different urban options.
- The objective is to evaluate environmental impact of urban planning.
- This study highlights the importance of an urban environmentally friendly design.
- Waste generated in the previous works on the lot should not be ignored.

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## ABSTRACT

In the framework of the integral construction of urban residences and buildings is necessary a previous study to analyze the evaluation and management of waste generated throughout the building process. This key ingredient of urban planning responds, in part, to growing environmental problems and a more acute awareness of the consequences that improper management of such wastes would entail. A previous quantification of the waste generated through construction – during the project stage – is needed so that the best building proposal may be chosen. Urban planners and policy makers should develop a keen eye for selecting cost-effective projects while environmentally friendly.

The aim of this paper is to study the production of waste in light of diverse urban solutions, both in the urban planning and building stages, as well as in global terms. To this end we studied six types of housing projects through simulations using statistical data, for different purposes, but with a common construction surface (50,000 $m^2$): (i) detached single-family unit; (ii) semi-detached single-family unit; (iii) 5-floor apartment block; (iv) 10-floor apartment block; (iv) 20-floor apartment block; and (vi) 40-floor apartment block. The main finding is that linear constructions generate a greater volume of waste than vertical construction, the difference reaching up to 57%.



## 1. Introduction

Construction and Demolition Waste (CDW) represents over one-third of the total solid waste in the world [1]. Clearly, buildings present a high index of environmental impact throughout their life cycles, and the generation of CDW contributes substantially to this environmental impact. Many materials are involved in building construction, so that choosing adequate materials and systems during the design stage is essential to reduce the future environmental impact of buildings [2]. This calls for knowing, with precision, the volume and type of the waste generated throughout the useful life of the building.

Wu et al. [3] highlighted the important benefits to be obtained from the economic and environmental study of waste management and organization when construction is underway. The design and selection of adequate material are key factors for reducing the environmental impact of a building [4]. Adequate knowledge of the types of waste produced and their quantity, at a regional level, is an essential step for the promotion of more realistic policies as well as the implantation of recycling methods.

The quantification and classification of waste from building construction can be approached at a macro or at a micro level. In their evaluation of the former, authors Cochran and Townsend [5] evaluated volumes of construction material and demolition waste in the US at a national level. Ding et al. [6] used statistical data at the national level to estimate the building and demolition waste generated in the region of Shanghai. At the micro level, previous work [7,8] has focused on analyzing a single building type.

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Although it is known that the specific building typology strongly conditions the type and amount of waste generated [9], little literature can be found in this respect. The typology and quantity of waste generated vary across the different phase of the buildings. In the phase of building construction, a greater volume of material and a vast proportion of the waste generated are associated with the movement of land. During the phase of residential building use, the volume of waste generated is more closely related with the tasks of maintenance, remodeling and reforms. In the demolition stage great amounts of waste are produced overall, yet especially if there are no recycling mechanisms involved [2].

Although the phase of use/occupation of buildings has the greatest environmental impact, it is also necessary to carry out studies that look into the rest of the stages [10]. A more detailed understanding should facilitate the implantation of mechanisms for a better management of waste, to ensure greater efficacy [11,12].

At the same time, this paper presents a classification and quantification of the waste generated during the stage of building for urban/residential purposes, establishing diverse urban planning scenarios, to compare results depending on the building type. The three most common residential building typologies are analyzed, and a total of 6 scenarios are evaluated [13–15]. For each scenario, the level of waste generated during the phase of construction was evaluated and a classification was carried out, considering as well the work of preparing the land for urban use.

The results obtained, together with the findings of a previous related study on $CO_2$ emissions for the same residential units under the same conditions [16], can be interpreted as a comprehensive evaluation of the environmental impact of the construction phase of different urban planning options.

The aim of this paper is to study the production of waste in light of diverse urban solutions, both in the urban planning and building stages, as well as in global terms. To this end we studied six types of housing projects through simulations, for different purposes but with a common construction surface. Our study takes in the most representative building types of the residential sector in Spain.

However, as non-standardized products, their properties depend on the design criteria applied in each project [4]. Instating measures for the reduction of environmental impact at the global level in a set of buildings in the design stage is no easy task. Notwithstanding, there is a dire need for the inclusion of urban planning criteria aimed for sustainable design and development. Integrating such measures in the design stage of a set of buildings—even if developed in the framework of different projects—may prove to be more efficient and cost-effective in the end analysis.

## 2. Material and methods

In this section are described the urban solutions used; the description of construction systems and quantification of materials; and the normative on waste classification.

### 2.1. Urban solutions

In this study, a hypothetical total surface allotment of 100,000 $m^2$ has been considered for designing different urban solutions. The plot to be urbanized was circular, distributed into:

- **Built area**. The buildable rate considered is 0.5 $m^2/m^2$ (roof/floor). Therefore, a total of 50,000 $m^2$ of land area would be occupied by residential buildings.
- **Assigned spaces for public**. According to the Spanish Rules for Development [17], a proportion of the urbanized plot must be devoted to public uses: school use, commercial use, social use and sport installations use. Summing up, public spaces represents the 12.87% of the plot area.
- **Leisure space**. The rest of the area is considered as free space.

According to previous studies [16], the most representative typologies of the residential stock in Spain are studied: detached houses, semi-detached houses and multi-familiar blocks. In the case of multi-familiar blocks, four block heights are considered: 5 floors height, 10 floors height, 20 floor height and 40 floor height.

In the case of single-family houses, each house corresponds to one dwelling. In the case of multi-family units, the built area corresponds to a set of dwellings. The floor distribution is the same for all the multi-family cases, varying the number of floors. For all the cases, one parking space per dwelling was to be situated underground (the underground surface not counting as living space).

The six urban designs studied are:

- **URB-1**. Residential development with detached single-family units (2 floors + tower).
- **URB-2**. Semi-detached single-family units (2 floors + tower).
- **URB-3**. Multi-family units, 8 blocks of 5-floor apt. buildings with one underground floor for parking.
- **URB-4**. Multi-family units, 4 blocks of 10-floor apt. buildings with two floors underground for parking.
- **URB-5**. Multi-family units, 2 blocks of 20-floor units, with four underground floors for parking.
- **URB-6**. Multi-family units, a block having 40 floors above ground and 8 underground floors for parking.

Based on the initial premise that the above-ground built area was 50,000 $m^2$, each design had a different number of buildings. Also, the distribution of roads, streets and free space varies from one urban solution to other. The land distribution and the differences between the different urban solutions are plotted in Fig. 1. Table 1 summarizes the building characteristics and urban features of the six urban options designed. More information on the design of the six urban solutions and the floor plans is given in a previous research [16].

Regarding normative purposes, the hypothetical plot of the study is located in the city of Granada (Spain), under application of the so-called *Land Law* [18] and the *Technical Building Code* (CTE) [19].

### 2.2. Description of construction systems and quantification of materials

Both the buildings as well as the civil infrastructures, were characterized with the most common construction techniques and materials in Spain. The buildings foundations were made of reinforced concrete slab. The structural framework was composed of columns and waffle slabs, also made of reinforced concrete. Double cavity brick walls, a traffic bearing roof as well as aluminum frame windows, compose the rest of the elements of the envelope. Indoor finishes are composed of ceramic flooring and cavity brick partitions walls with plaster and painting layers.

Regarding the civil works, sidewalks are made of hydraulic flooring on mass concrete and gravel subbase. Both the kerbs and water lines on the sidewalks are composed of pieces of granite on a concrete base. The road network is composed by two layers of asphaltic concrete on a base of artificial gravel and natural gravel. Water supply system is composed of cast-iron pipe. In the case of sewage network, it is composed of concrete piping for diameters greater than or equal to 0.6 m and PVC piping for smaller diameters

The gas supply network is solved with HDPE pipeline. The electricity grid, lighting network and telecommunications network is solved by a PVC piping of variable diameters according to the standard. The water supply system, sewage network and gas supply network were placed on a bed of sand, whereas electricity network, lighting and telecommunications were placed on a bed of concrete.

The materials involved in foundation and structure (mainly concrete, cement and steel) are responsible of a great part of the environmental impact of housing construction [20–22]. In our study, the foundation and structure were calculated in accordance with the direct stiffness method. The output of this calculation was the description and quantity of those materials involved in these task, for each of the six case studied.

In the stiffness method, the relation between the stresses and deformations of the bar elements was assumed to be linear with six degree of freedom per node. The relation between the stresses of each element and the displacement was based on the equation $f = K \cdot D$, where $K$ is the stiffness matrix of the element, and D is the displacements of the nodes. This calculations were performed with the software program CYPECAD [23], under license by the University of Granada.

All the necessaries task for the construction of the buildings and the development of civil infrastructures were grouped into construction work units, listed in Table 2.

The materials involved in each task unit during the construction phase, were quantified. More information on the quantification and distribution of materials is given in a previous work [16]. The construction material quantification was the basis for the estimation of the waste generated in the construction phase.

### 2.3. Normative on waste classification

Previous studies [24] regarding waste assessment on different stages of the building do not agree about the distribution of waste generated, especially with respect to the waste of lesser volume. Such classifications should, ideally, be undertaken with reference to the legislative framework of the European Union, specifically in view of the List of European Waste (LOW) [25].