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Simulation and comparative analysis of waste in concrete slabs

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***Abstract*— Construction sector generates significant amounts of waste that affects the environment and obstructs a sustainable development. The horizontal structure (slabs and roofs) is one of the building elements, by its functional requirement (geometry and layout) and volume, who uses more raw material for its constitution (potential generators of waste) On the other hand, the choice of the system to use, is typically based on criteria such as the ease of construction, the economy availability or the technological feasibility; so, from a sustainable perspective, the generation of waste has not been considered or evaluated. This work compares and analyzes four different common elements used in slabs and the possible generation of waste produced for the construction and eventual demolition of them, in order to provide a new weighting criterion in the choice.**

***Keywords*— waste in construction, waste simulation, sustainable construction, types of slabs.**

I. Introduction

A. General context

Currently, there is a consensus on the need to integrate aspects related with the wastes that are generated in the preliminary stages of a project (planning and design), to avoid the generation of significant quantities of waste in the Construction and Demolition (RCDs) during and after the execution of the project [1]. Notwithstanding the foregoing, the waste management is presently the objective getting less attention in the design and planning of construction projects, prevail the costs and construction times as the decisive [2].

The building industry is one of the sectors that generate more waste, with a considerable environmental impact, but the absence of consciousness by those involved in the construction business, does not perform effective waste management, including in some cases, not managed [3]. Therefore, to direction towards sustainable construction, the proper choice of materials and construction techniques must be done.

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The materials used in the construction industry affect the environment along its entire lifetime. This can be classified into four stages: 1) extraction and processing phase, being the most significant stage, 2) manufacture or production phase, 3) employment phase, less known but not less important, and, 4) waste phase.

The excessive consumption of these materials, natural resources and the environmental impact that its continuous extraction have caused, have made necessary to reduce, reuse and recycle the wastes generated by the building industry: to reduce in order to decrease the volume produced, to reuse in favor of the employment of them again without the necessity to transform them, and to recycle for using the material as a new product. Also, other alternatives are needed to improve environmental management, as well as sending the minimum amount of waste to landfill, minimize the use of materials and make new cleaner processes [4].

The European Union generates about 450 million tons of construction waste and demolition (RCDs), of which between 30 and 40 million RCDs tons are produced in Spain (between 6% and 9% of total). At present, reuse and recycling is the 28% at European level, but only 5% in Spain, which states improvement areas in the building industry. It could be very difficult to change the present-day construction, but it is possible to reduce waste, decreasing consecutively the management costs and the amount of raw materials, in order to obtain a positive environmental outcome [5].

B. Study object

In light of the above, this work aims in a statistical comparative analysis with weighting factors including waste from unidirectional and bidirectional concrete slab systems. This analysis will produce, under equal conditions of service for each of the cases, the contribution ratios and ratios of similar comparisons. Four systems will be integrated within a housing project for the recognition of its proper comparative analysis.

A waste estimation will be done by the computer program “The Net Waste Tool” (NWT) [6], which determines solutions to reduce the elements of study, comparing different systems, and making a list of sustainable alternatives for each type of waste generated by each studied slab, in order to evaluate alternatives for reuse and recycling, compared to those that currently exist in the environment studies.

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Final conclusions will be drawn by comparing the results and relevant data, thus determining which analyzed system is the most suitable, from a sustainable point of view, that is, more efficiently and with less environmental impact.

C. *Building Description and types of studied slabs*

The studied building is located in Gracia District, Barcelona, Spain; a single-enclosed-between-wall building; it has three parking stories, two commercial stories, four housing stories and roof. Its distribution is as follows:

Floor (F) parking (P) (-4, -3 and -1) have 16 and 14 park places (-4 and -3), and without distribution (-1); all of them has an elevator, exit stairway and access ramp to the parking lot. Low floor (LF) Stores (S) (without distribution): access ramp to the parking lot, two elevators, exit stairway to street and lobby for access to housing areas. Mezzanine and first floor Stores (without distribution both): stairway and two lifts for access to housing and roof. Housing Floors (HF) (Second, Third, Fourth and Fifth levels): eight apartments, common spaces, corridor to housing access, stairway and two elevators to housing and roof access. Story -2 has a management office. The roof is covered with solar panels and machinery, staircase and two elevators. Table I presents the areas and uses established for the study. Table II presents a general description of the studied building, detailing elements, materials and specific properties.

TABLE I. BUILDING AREAS AND THEIR USES

Floor (F)		Use	Area (m^2)
Roof		CA	192.80
2, 3, 4 y 5		HF	517.50, 51750, 517.50, 546.35
1		S/HF	507.85/26.65
Mezzanine		S/HF	416.35/26.65
LF		P/S/S/CA	104.00/375.35/97.20/6.05
Basement	-1	P/S/CA	271.90/301.15/37.55
Basement	-2	P/CA	596.75/19.45
Basement	-3, - 4	P/St	616.20, 616.20
Total			6354.95

CA. Common areas, St. Storage

Figure I show the alternatives analyzed in this work as possible constructive solutions for slabs, with diagrams of typical sections, as well as the features obtained in their calculation.

The selection criterion to choose the alternatives was that they were feasible to build (leaning slabs and P-1 are considered as not feasible) and common in the local industry.

TABLE II. BUILDING ELEMENTS STUDIED

Classification					Material/specification	Thickness (cm)
Elements of the Structure	Foundation				Concrete*: HA-25/P/20/IIa; Steel*: B500SD	Variable
Elements of the Structure	Retaining Walls				Concrete*: HA-25/P/20/IIa; Steel*: B500SD	Variable
Elements of the Structure	Elevator walls				Concrete*: HA-25/P/20/IIa; Steel*: B500SD	20
Elements of the Structure	Type of Slab	Leaning	Stairway	HF	Concrete*: HA-25/P/20/IIa; Steel*: B500SD	20
Elements of the Structure	Type of Slab	Leaning	Stairway	B-2 to LF	Concrete*: HA-25/P/20/IIa; Steel*: B500SD	25
Elements of the Structure	Type of Slab	Leaning	Stairway	B-1 to F1	Concrete*: HA-25/P/20/IIa; Steel*: B500SD	28
Elements of the Structure	Type of Slab	Leaning	Ramp for vehicles (K)		Concrete*: HA-25/P/20/IIa; Steel*: B500SD	25
Elements of the Structure	Type of Slab	Horizontal	B-1		- One-way floor slab: Prestressed joists.	35
Elements of the Structure	Type of Slab	Horizontal	B -2,-3,-4 LF F1, 2, 3, 4, 5		- One-way floor slab: Parallel joists. (**E-1**) - One-way floor slab: Lattice joists. (**E-2**) - Waffle slab: Lost filler blocks. (**E-3**) - Flat Slab (**E-4**)	35
Elements of the Structure	Type of Slab	Roof	Walkable roof (ventilated)		(as above)	35
Elements of the Structure	Type of Slab	Roof	Not walkable roof (lift)		(as above)	35
Walls	Lateral walls				Perforated brick (LD**), Category I (290x140x100 mm), positioned to cover with mortar mixed with cement CEM II (1:2:10)	29
Walls	Interior Walls	Walls between housings			Perforated brick (HD**) Category I (290x140x100 mm) to be coated.	14
Walls	Interior Walls	Interior walls of an apartment			Gypsum drywall ** structure: galvanized steel profiles, each 400 mm (70x70 mm width and channel), standard plate 15 mm thick on each side, mechanical fastening and insulation board with rockwool density 26 to 35 kg/m^3.	10

*[7], **[8], Note: In blue, the study items.

All the cases were subjected to the implementation and verification of the structural code [7], as well as the requirements of their use, such as:

- Technical Code for Construction [8]: Basic Document of security in the event of a fire (DB-SF), Basic Document for Protection Against Noise (DB-PN) and Basic Document for Healthiness (DB-H).
- Royal Decrees: 14/2012 (minimum heights between slabs, and between slab and slab on-grade) [9] and 486/97 (minimum heights in commercial and office spaces) [10].

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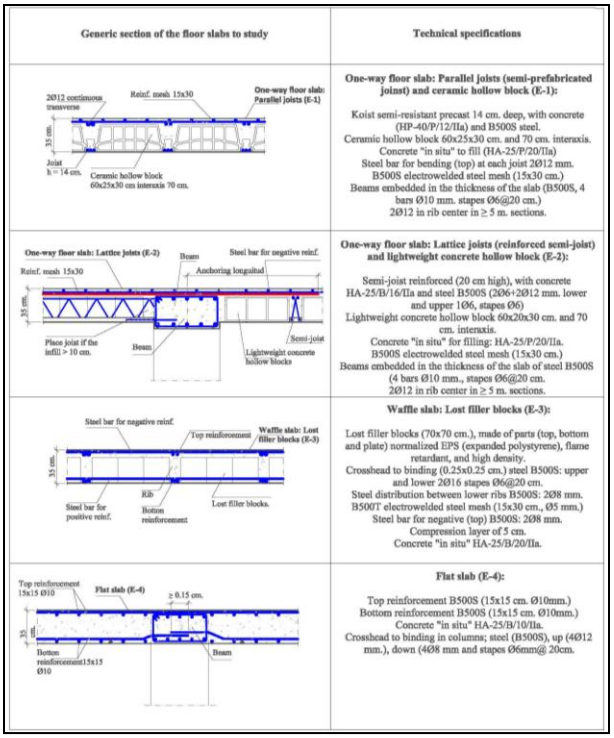

Figure 1. Selections of the studied slabs and mechanical definition of the elements.

II. Process to obtain data

A. *Simulation for obtaining residues*

For the simulation analysis, the free software for waste management in the construction industry, Net Waste Tool [6], was used. Data from four variables studied were introduced in the program: type of construction, costs/m^2, units to build (m^2), percentage that the c/r materials represent in the total price per m^2 to build (%), geometric characteristics, volumes (m^3/unit), density (t/m^3), theoretical content of material viable to recycle (%), packaging details, baseline wastage rate (%), and material composition based on the European Waste Catalogue (EWC) (%) [11].

Once data has been entered, the tool uses this information to estimate the waste levels and to identify specific actions to reduce the amounts of waste generated. By the means of the information about the cost of the different waste flows, it identifies which of them will provide greater reduction of the cost if they are separated out of the flow of the mixed wastes, in addition to the opportunity to plan and organize the waste containers throughout the construction period.

In the last part of the analysis, the system determines the appropriate destination of each residue previously separated in the construction, considering the recovery of waste by the contractor and estimating the anticipated amount of waste destined for landfill and the amount likely to recover.

B. *Analysis of results*

The NWT system allows access to reports of waste generated in weight (t), volume (m^3) and cost (€) for each of the systems. The obtained results were then statistically analyzed to determine similarities, differences and trends of each studied system, in order to establish measurable and sustainable approach with information in the most appropriate selection for future building proposals.

The total amount of waste in tons and cubic meters for each simulated system are: **E-1)** 5163 tons and 3506.52 m^3; **E-2**) 5109 tons and 4164.76 m^3; **E-3**) 4179 tons and 2406.41 m^3; and **E-4**) 3195 tons and 2228.91 m^3, allowing to see the importance and allocation (at different intensity levels), which may generate the waste in the construction of a multi-family housing [12].

Figure 2 presents the total values for specific waste in each studied slabs system, where concrete and steel are the materials with the highest incidence of waste.

For the specific case of concrete waste, **E-2** (One-way floor slab: Lattice joists) is the one which generates the greater amount of, while the greater amount of metals and steel residue, the **E-3** (Waffle slab: Lost filler blocks) is the leading. The above may reveal that these two elements can be more pollutants and less sustainable than the others studied. Finally, for concrete the most appropriate unit to measure the waste is cubic meters (m^3), while for metals and steel is tons (T), because, in both, each one represents a bigger range than the other respective unit.

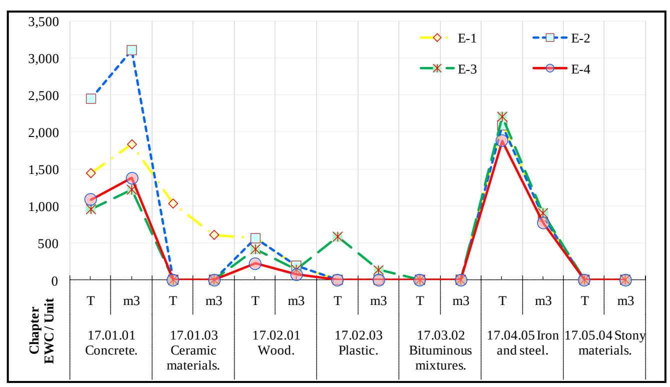

Figure 2. Total waste by type and classification of elements (EWC).

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Processing the results of Figure 2 through the division of each residue by the total quantity of waste (Tons or m^3) and expressing them as percentages, Figure 3 allows to verify that for concrete, the **E-2** element will produce more waste. For ceramics materials, the **E-1** option produce more waste; and for wood, it will be the **E-1**, **E-2** and **E-3** options with similar values. In addition, for plastic and bituminous mixtures options **E-3**, by far, and **E-3** and **E-4**, with minor significance with respect to others systems, produce more waste, respectively. Finally, for metals and steel, options **E-3** and **E-4** produce more waste, while for stone materials, it is almost indifferent and insignificant its evaluation in the four studied systems.

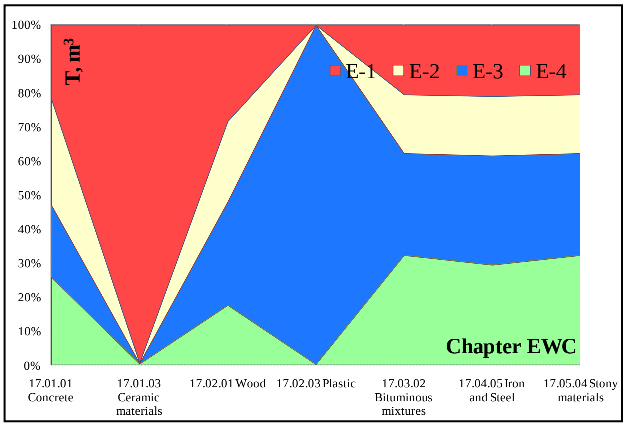

Figure 3. Residues generated in the studied systems by percentages.

To perform a more accurate statistical comparison on the subject of the produced residues, the values obtained in the simulation were normalized with five criteria, common to the four studied elements: price of materials execution (€), concrete consumption (m^3), steel consumption (kg), wood consumption (m^2), and workforce (hours). For the abovementioned, each obtained value of residue (tons, m^3) was divided by the calculated value of each of the parameters of normalization, for every studied element.

Thus, with this process, sensitivity coefficients were defined for each parameter of standardization, with validity for comparison between them, or to extrapolate to others constructions, research studies or inference from other constructions in design phases, as can be observed in Figure 4. As shows this figure, the shape of the curves is substantially the same in all of the studied parameters of normalization. On the other hand, the graphics "move" along the vertical axis, thus enabling to induce the sensitivity ability to the studied phenomenon for each parameter.

Therefore, the parameter workforce (h) in Figure 4e would make possible a more accurate control of waste (maximum range of the variable); being not usual for the worksite control, it would permit a maximum sensitivity to determine limits and to be a decision parameter. Furthermore, the parameters with cubic meters and square meters (see Figure 4b and 4d, respectively), the most common for the worksite control, are the next to submit a maximum range of the variable, and therefore, strong sensitivity, ability to control and prediction of waste.

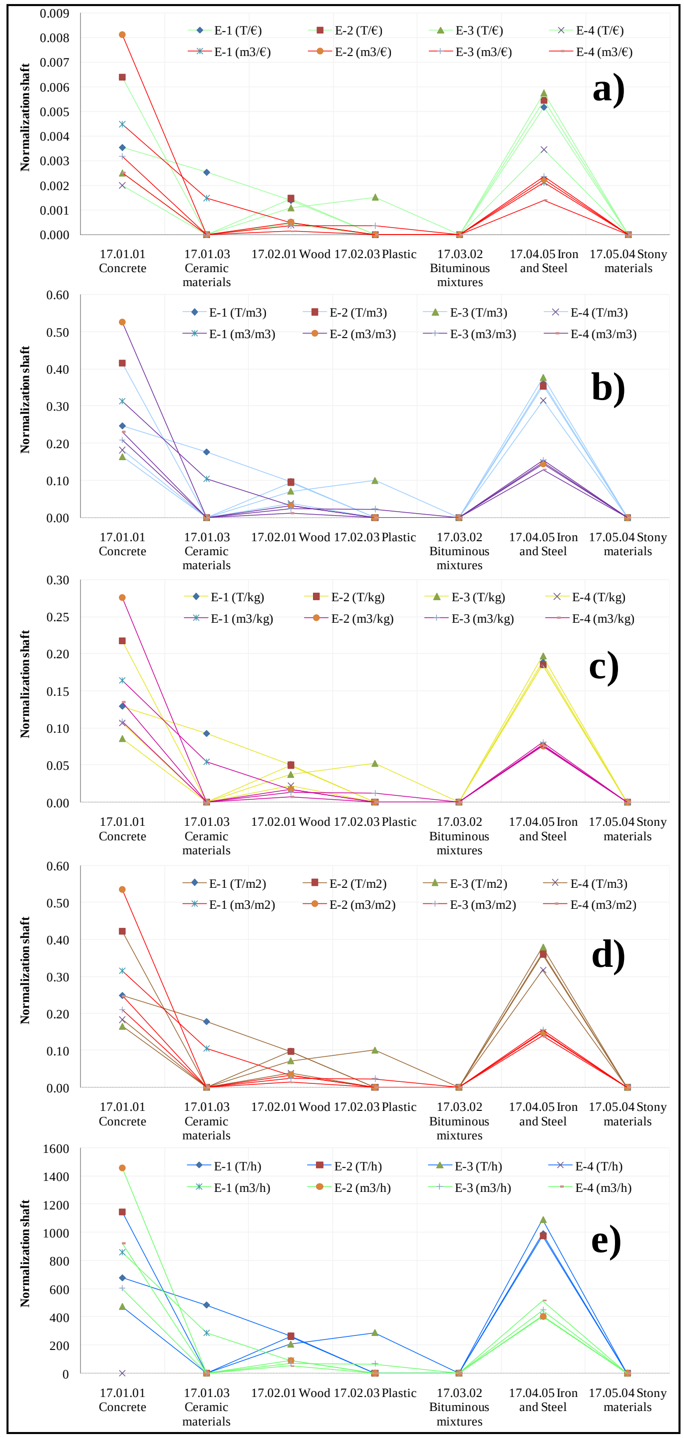

Figure 4. Normalized residues production based on the sensibility of the coefficients.

Finally, it is important to indicate that the units of data in Figure 4, allow them to be compared or to be used as a parameter of estimation in similar works.

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III. Conclusions

A. *Generals*

The determination of the types and quantities of waste to be generated in the construction, either in the design phase or during the construction process, is a factor that enhances the potential of the sustainability. Directing a preliminary material selection process, will reduce the waste and consequently the environmental impact.

It is possible to affirm that, according to the sustainability perspective and environmental care, the choice of the type of slab to employ could be qualified as efficient. Nowadays this sustainable approach of selection should also be considered as an additional parameter to take into account to define an optimal concrete slab.

B. *Specific*

The determination of the types and quantities of waste to be generated in the construction, either in the design phase or during the construction process, is a factor that enhances the potential of the sustainability. Directing a preliminary material selection process, will reduce the waste and consequently the environmental impact.

The normalizer parameter of workforce and the units of measure cubic meters and square meters, have higher sensitivity coefficients, with greater range of variability. They are the most sensitive to determine limits, therefore they must be selected as decision parameters.

Considering the analyzed results from a comparison of the waste in all the systems, based on the homogenization parameters, the Flat Slab (**E-4**) is the system that generates lower quantities of waste; that is, a lower environmental impact. The next, in descending order, are: the Waffle slab (Lost filler blocks) (**E-3**), One-way floor slab (Lattice joists) (**E-2**), and finally, the One-way floor slab (Parallel joists) (**E-1**), the one with more waste production (anecdotally the most currently used by its potential to build).

With regard to the type of material produced by slabs, the concrete and steel are, in a considerably extent, the ones to end as residues; because of this, it must be to anticipate, monitor and manage them, in both, design and construction phases.

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