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Comparative by simulating the eventual waste generation of building indoor pavements construction

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Abstract The construction sector affects the environment through CO₂ emissions generated by use of massive quantities of materials, energy, and waste during the construction and demolition process. Moreover, current technology offers a wide variety of materials, products and construction systems that could be used for a similar solution; however, the decision to select one or other element lies with the price and then by regulatory requirements and availability (ignoring the issue of sustainability). In an apartment building, the pavements are one of the elements with major representativeness and more possibilities of alternative variables in its materials; so, this research expose three different types of pavements with similar prices, comparable functions, and normative compliance, but providing a new sustainable perspective: The construction and demolition waste (C&DW) analysis. The results (simulation of waste) evidence the differences between the wastes generated from each type of pavement, pointing that the application of sustainable management criteria can be significant for sustainable buildings construction. This research shows a new criterion applicable to the construction sector that could improve the selection (with equal requirements) of one type of pavement into a more environmentally friendly pavement, allowing the achievement of profits for the builders.

Keywords-building pavements; material selection criteria in construction; selection of sustainable materials; sustainable construction; waste simulation

I. INTRODUCTION

Currently, one of the biggest challenges facing the planet is caused by waste generation and their accumulation in landfills, being the construction and demolition waste (C&DW) the most representative [1].

In a building, different construction phases arise including the execution of pavements; which are considered as the elements with the larger horizontal surface, being one of the main causes of C&DW [2]. In this research, the wastes generated (construction and eventual demolition) by three types of usual interior floors in Spain are analyzed, compared and quantified through simulation. The basic objective of this research is to establish and identify which type of pavement

generates more wastes, what are they and what relationship maintained between them.

Three types of pavements were applied in the same case study (multi-family housing located in Barcelona, with a pavement total area of 2,341.00 m²); The constructive application was equivalent and with comparable feasibility of use; the selected pavements were: Indoor terrazzo tile (P1), ceramic rustic tile (P2) and Spanish granite tile (P3).

We used the Net Waste Tools software (NWT) (with the data of the selected pavements) as a simulation tool, this allowed us to obtain reports for each pavement type, finally, these reports were standardized to make a comparison. The results indicated that, although the analyzed pavements could be used (solving the technical requirements, regulations, difficulty of construction and similar prices), their estimated waste generation is not the same for all of them, enabling us to highlight that this type of analysis can perceive differences which have passed unnoticed by the construction sector so far, with an additional contribution to be a new approach that promotes sustainability, environmental care and financial savings for the sector.

II. BODY OF KNOWLEDGE

It is expected that the world population growth will double before the middle of this century, accentuating in urban and surrounding areas. If we take into account the limitations of building areas in big cities, the building sector seems to be forced to define new solutions to this problem [3] and the validation of building systems for sustainable housing, could help in this regard. Between the different elements in a building construction, the indoor pavements have not yet been linked optimization criteria for its sustainable ratification (despite exist variety of systems and similar constructive solutions); While it is true that the use of more complex systems (diversity of materials and construction processes of placing wet) may be less sustainable than those using less diversity of materials, and putting in work it is simpler.

In Spain, during the period from 1990 to 2007, housing construction, urbanized areas and infrastructure came to report an increase of 40%, which led to an increase in material consumption over 141% in that period [4] (including pavements).

Moreover, the sustainable development and thus the sustainable construction has become an increasing concern to the globe, through the comprehension of the contamination effects over the environment. In the United States, building sector represents 38.9% of the primary energy consumption, 38% of all CO₂ emissions and 30% of waste generation [5]. In the European Union (EU) building construction consumes 40% of primary energy, 40% of all materials and generates 40% of wastes [6].

The EU report nearly 450 million of tones per year, only 25% of which are retrievable [7]. Whereas in Spain, it is estimated that 70% corresponding to wastes from activities related with C&DW [6]. In addition, CO₂ emissions in the residential, commercial and institutional sectors report an increase of 65% in comparison with 1990 [8].

With respect to the foregoing, it is important to emphasize that building indoor pavements represents a contrasting environmental impact. Housing buildings, particularly indoor pavements should be evaluated by comparable criteria that will allow its apocryphal pounding on waste generation and recycled material used for its process with an adequate construction system.

In Spain [9], the construction sector produces around 40 million tons of residues, reaching 32% of the total volume; if the previous hypothesis refers to uncertainty which presents the C&DW of different building pavements generation was verified, it could be argued and contribute to savings in raw materials, conservation of natural resources, environmental preservation, protection of public health, the use of recycled material [10], waste reduction and in the wider context, to sustainable development. Therefore, the sustainability on construction could bring new solutions to current society paradigms; one of these could be the establishment of new environmental criteria (minimum C&DW generation) on the constructive systems (indoor pavements), that satisfying the normative or the operational use criteria but being sustainable at the same time.

III. ELEMENTS, MATERIALS AND METHODS

The case study (41°24'17.6"N 2°10'12.8"E) is located on a lot of 705.60 m² of which 346 m² are buildable. The building counts with 34 houses and one commercial unit on the ground floor. Floors are distributed as follows: One basement, a ground floor and eight floors type (four apartments by floor) and upper attic (two apartments). The type-apartment has the following distribution of spaces: Living/dining room, kitchen, four bedrooms, bathroom and separate WC and sink (See Fig. 1).

Figure 1. Distribution of spaces.

The pavements of the study correspond to the total communal areas and housing; for each type of use, a type of pavement was selected which complies with the requirements of the Spanish regulation (SU1 Security against the risk of falls, and DB-SUA utilization and accessibility Security; by the CTE Technical Code of the Edification).

Figure 2 shows geometry and configuration per square meter of pavement, the materials and surface thickness defined in the simulating waste analysis are the following: Indoor terrazzo tile (P1), ceramic rustic tile (P2) and Spanish granite tile (P3).

For each pavement, quantification by square meters of the prices, yields, loss of waste, packaging materials and densities used in the simulation were obtained from the database: Prices of construction generator by the CYPE S.A.V. 2015i software (www.cype.com). Table 1 shows the headings of each pavement, indicating specific quantities and prices of inputs materials that were used in the simulation.

Figure 2. Geometry and configuration per square meter of pavement.

TABLE I. DESCRIPTION OF PAVEMENTS

P 1				
Unit	Description ^a			
m ²	P1 (Terrazzo flooring). Tile flooring terrazzo medium grain (6 to 27 mm), classified normal use for indoor, 40x40 cm, beige, positioned at blow pot on a bed of cement mortar, industrial, M-5, and grouted with white cement grout BL-V 22.5 colored with the same tonality of the tiles.			
Unit	Broken down	Performance	Unit price	Item price
m ³	Water	0.011	1.50	0.02
t	Industrial mortar for masonry, of cement, grave, class M-5 (compressive strength 5 N/mm ²), supplied in sacks, according to UNE-EN 998-2.	0.060	32.25	1.94
m ²	Indoor terrazzo tile, normal use, medium grain (6 to 27 mm), nominal 40x40 cm, beige colour, with a first polishing in factory, for polishing and buffing final in work, according to UNE-EN 13748-1.	1.050	10.25	10.76
kg	White cement BL-22.5 X, for paving, in sacks, according to UNE 80305.	1.000	0.14	0.14
kg	Grout colored with the same tonality of the tiles, for terrazzo paving.	0.500	1.15	0.58
h	Official 1st welder.	0.192	17.24	3.31
h	Assistant welder.	0.354	16.13	5.71
%	Auxiliary resources	2.000	22.46	0.45
%	Indirect costs	3.000	22.91	0.69
Ten-year cost of maintenance: 2,12€ in the first 10 years.			Total:	23.60
P 2				
Unit	Description ^a			
m ²	P2 (Ceramic tiles flooring with cement as a bonding material). Ceramic tile flooring rustic tile, 3/2/H/-, 30x30 cm, 15.13 €/m ² , received with white cement mortar BL-II/A-L 42.5 R M-5 of 3 cm thick and grouted with cementitious mortar joints with high resistance to abrasion and reduced water absorption, CG2, for minimum joint (between 1.5 and 3 mm), with the same tonality of the pieces..			
Unit	Broken down	Performance	Unit price	Item price
m ³	White cement mortar BL-II/A-L 42.5 R, type M-5, made on site with 250 kg / m ³ cement and a volume ratio 1/6.	0.030	88.34	2.65
m ²	Ceramic tile rustic tile 3/2/H/-, 30x30 cm, 15.13 €/m ² , according to UNE-EN 14411.	1.050	15.13	15.89
kg	Cementitious mortar joints with high abrasion resistance and reduced water absorption, CG2, for minimum joint between 1.5 and 3 mm, according to UNE-EN 13888.	0.100	0.99	0.10
h	Official 1st welder.	0.273	17.24	4.71
h	Assistant welder.	0.137	16.13	2.21
%	Auxiliary resources	2.000	25.56	0.51
%	Indirect costs	3.000	26.07	0.78
Ten-year cost of maintenance: 4.56 € in the first 10 years.			Total:	26.85
P 3				
Unit	Description ^a			
m ²	P3 (Natural stone flooring with cement mortar as a bonding material). Granite tile flooring Grey Villa, interior, 60x40x2 cm, flamed finish, received with cement mortar M-5 and grouted with cementitious mortar joints, CG1, for minimum joint (between 1.5 and 3 mm), with the same tonality of the pieces.			
Unit	Broken down	Performance	Unit price	Item price
m ³	Cement mortar CEM II/B-P 32.5 N type M-5, made on site with 250 kg / m ³ cement and a volume ratio 1/6.	0.032	115.30	3.69
m ²	Spanish granite tile, Grey Villa, 60x40x2 cm, flamed finish, according to UNE-EN 12058.	1.050	30.05	31.55
kg	Cementitious grout, CG1, for minimum joint between 1.5 and 3 mm, according to UNE-EN 13888.	0.150	0.70	0.11
h	Official 1st welder.	0.314	17.24	5.41
h	Assistant welder.	0.314	16.13	5.06
%	Auxiliary resources	2.000	45.82	0.92
%	Indirect costs	3.000	46.74	1.40
Ten-year cost of maintenance: 4.33 € in the first 10 years.			Total:	48.14

a. According to CYPE S.A.V. 2015i software.

The above data were implemented in the NWT tool that allows designers, builders and contractors to increase the efficiency of use of materials and comply with legislation of its management; since this, quantifies and determines the type of waste, evaluates the use of resources, cost reports and quantities of waste to generate and provides comparative strategies.

IV. RESULTS AND DISCUSSION

Figure 3 shows the results from NWT, partial expressed in percentages of each pavement studied in tones and grouped according to the European Waste Catalogue (CER).

Figure 3. Waste components generated on each pavement.

Both for P2, as to the P3, only two materials are expected to generate: concrete in both cases; and ceramic, stone and land, respectively. Finally, for the P1 are expected to have: concrete, concrete and ceramic combination and borated. In all three case studies, the material is always present is the concrete (with average values of 14%); however, the most representatives (average of 85%) are ceramic materials or mixtures thereof with other, reflecting the difficulty of a single feasible segregation (P2 except that produce not combined ceramic).

With respect to the evolution of possible implications during the construction of the study cases through a standard or

conventional (without sustainable criteria) waste management and a desirable or ideal waste management (with sustainable criteria); and implementing as a normalization criteria of data, the selected variables according to the size of the tile (a), the construction cost (b), and the amount of tiles per square meter (c). Figure 4 shows to the comparative studied pavements (for a1, b1 and c1 per tones and cubic meters respectively, and for a2, b2 and c2 per value of waste generated respectively).

In the case of a1, b1 and c1, the waste generated by the P3 are the most volume and weight producer (Concrete and ceramic materials mix), also in the three cases, the standard management produce significantly more waste when compared with the desirable management. And finally, the unit of cubic meters proves to be the most representative form of measurement. Of these three graphs, standardization criteria that best allows us to discern the behavior is the size of the tiles (highest numerical scale in the vertical axis).

In terms of a2, b2 and c2, the waste which presents the highest value varies according to the normalization criteria: for a2 is the P2 (ceramic materials), for b2 and c2 is the P1 (land, stones and others); considering the amount of tiles per square meter like the most sensitive criterion of normalization of the three cases. Moreover, in all cases the standard management always generate more wastes than the desirable management.

V. CONCLUSIONS

This paper shows that the establishment of waste minimization techniques and an adequate management, brings financial benefits for the construction and environmental benefits for the site, because avoid unnecessary materials use and generate less waste during the execution process; which was particularly evidenced by the differences in prices and volumes of the “desirable” and “standard” C&DW management (by the NWT simulation).

Figure 4. Desirable and standard management of the pavements according to: a) size of the tile; b) construction cost; c) amount of tiles per square meter.

Option P3 was the most expensive in terms of management, followed by option P2 and finally P1. The cost difference between P1 and P2 is not significant. But P3 is exceeded by more than double the material and construction cost of the P1.

The total cost of recycling indoor pavement materials turned out to be more in a "standard" management than in a "desirable" (given that in standard management it is not widely applied minimization techniques). This "desirable" management cost was found in cases with a negative value because the value of the incorporation of recycled and reused materials in the construction is greater than the value of waste disposed of; therefore, the total cost of recycling is zero (earn a profit).

The option P1 has the most negative value, that means that the option could have the lower recycling cost due to their high recycle content concerning other options; therefore, there is a better chance of recovering materials. In the case of obtaining waste reduction performance, the highest occurred on option P3 with 26.61% on tons of waste reduction and 38.53% on containers cost reduction, in spite of the increase in the value of recovered materials only became to 10%.

Moreover, the reduction of the types of waste in a desirable management over a standard it is of 37.50% in all cases (weight, volume and cost); it, therefore, be argued that the application of waste minimization techniques and the establishment of an appropriate waste management will generate economic and environmental benefits, given that the tones of materials intended for landfill, the volume that they occupy, and the cost will be less.

Weight and Volume of the tiles were the best parameters than describe and allows the establishment of the correlations between different variables, being prescribed like the decision parameters for the final election between sustainable indoor pavements.

Different types of generated waste on simulation were grouped into two areas: Tiles materials and concrete; tiles materials have the highest quantity of waste. The common material in the three options was the concrete, reaching rates with respect to the rest of materials of a 15% for the P1 and P2, and an 11% for the P3.

Analyzing the construction systems studied, it was observed that P1 generates the largest quantity of wastes (greater thickness and hence higher weight and volume); while

the P2 (thinner tile and mortar) reports the least amount of waste weight and volume. This denotes that the volume and density of materials (tiles and concrete) influence the generation of waste material.

Finally, although the P3 is a natural stone and Spanish legislation recommends this pavement to be considered for use in any space, in this research, it turns out to be that higher cost is in construction and lower percentage of recovery of materials can reach (caused by the manufacturing process); but on the other hand it is the one that gets a higher yield by applying a "desirable" management of waste (by weight and volume).

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