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Estimating Building Construction Costs by Production Processes

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Abstract: Building actors need accurate estimates in order to efficiently undertake the construction of buildings. The knowledge of real expected costs of construction works is a necessary condition for contractors to submit competitive tenders and for developers to be aware of the magnitude of their investment. In this paper, an innovative process-based model is presented, the POP model. This model aims at providing building actors with a systematized methodology to calculate building construction costs based on the planning, organization and scheduling of the expected works. Unlike the model of construction work units, the most widespread estimate model in Spain, the POP model comprises all construction costs in a direct way by identifying the production processes involved and the resources consumed, giving a new approach to the principles of the activity-based costing methodology in tune with the process-based cost models that are emerging in the international scene. Nowadays, the model is being applied in real construction works with satisfactory results of transparency, detail and adaptability. Not only reliable estimates are obtained, but also the performance of works is devised, allowing its optimization and control.

Keywords: Activity-based costing methodology, construction economics, estimates, planning, organization and scheduling, process-based model.

1. INTRODUCTION

In the Spanish construction industry, the current international crisis has revealed a lack of competitiveness that requires a series of structural changes in order to improve the efficiency of the traditional production system. Since this efficiency is defined as the ratio of results obtained to costs incurred [1] and the optimization of any production system is achieved once its life cycle efficiency is maximized, the optimization of any system with an expected result can only be carried out once economic, environmental and social costs are minimized.

The building construction industry is a complex system made up of multiple interrelated production processes, whose main goal is to satisfy real estate demands by developing big products, termed buildings [2], through distinct stages [3] that start from an initial state characterized by a lot or an existing building. In order to be a sustainable and competitive industry, this aim has to be achieved from a balance among economic, environmental and social requirements [4] that can only be attained by innovating different elements of the system such as production processes, resources, tools and skills.

Many authors [5] agree that sustainable construction is supported by three main pillars: people (society), planet (environment) and profit (economy). Only by reaching their equilibrium, it is possible to achieve a construction able to satisfy present needs without endangering future ones [6]. As far as the economic dimension is concerned, a sustainable construction can only be reached if construction works are economically feasible and reasonably profitable for all building actors involved. In this regard, estimates are an essential tool for building actors in order to measure construction costs before they occur and evaluate their feasibility and profitability. The more accurate an estimate is with respect to the actual cost of the project, the more reliable the information provided becomes and the better decision-making processes can be tackled on the building site.

In this context, the objective of this research is to develop a construction estimate model that provides elaborate information of construction costs taking into consideration the real structure of the building construction system, promoting the development of transparent, feasible and controllable projects. Our proposal, the POP model[1], derives from the revision of the model designed in the doctoral thesis of the corresponding author [7] and aims to provide the real costs of construction works in a transparent way by simulating their planning, organization and scheduling. The knowledge of these costs, before they are generated, allows building actors to control building works in order to achieve expected results. Furthermore, it enables to optimize the system from different planning alternatives and to choose that one of minimum cost. Following the basic guidelines of the activity-based costing (ABC) methodology, which was created by Cooper and Robert Kaplan [8] in the mid 80's, and the principles of process-based cost (PBC) models, our proposal approaches to estimate models used by Spanish construction

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[1] The acronym derives from its Spanish original denomination, *"Presupuestos de Obras por Procesos"* [Process Based Estimates].

companies in order to standardize them and provide building actors with a common language of communication.

2. ESTIMATE MODELS

In Spain, the estimate model that has traditionally been accepted as an irrefutable paradigm supported by Spanish law is that based on construction work units [3]. This is practically the only model that concurs in the economic analysis of the works in the Spanish construction industry and all the steps that have been taken in the pursuit of efficiency of estimate models have been directed towards its improvement [9, 10] as well as in the development of different classification systems of construction work units such as that of the Andalusian Foundation of Coding and Construction Database [11]. The main characteristic of this model is the existence of two types of costs in the construction estimates: direct costs and indirect or overhead costs. The former correspond to resources directly involved in construction activities, whereas the latter, mainly related to building site logistics, appear as a percentage of direct costs. For a comprehensive analysis of this model we refer to the book of Ramírez-de-Arellano [9] entitled *"Presupuestación de obras"* ["Construction estimates"].

Even if the estimate model of construction work units has allowed, so far, the maintenance of a reasonable balance in the economic relations between Spanish building actors, the critical situationthat construction industry undergoes at present, owing to the financial recession, demands to improve the efficiency of estimates by adapting them to the reality of building site processes. In this regard, there is no place for overhead costs included as percentages in the estimates, because their nature of fixed costs is being distorted. A new estimate model for the Spanish construction industry is therefore required.

In the international scene, Akintoye and Fitzgerald [12] exposed and analyzed in 2000 the different techniques of cost estimating that were used in UK at that moment. They observed that the three methods that were mainly used by the construction contractors were those of estimating standard procedure, comparison with similar projects based on documented facts and comparison with similar projects based on personal experience. Similarly to the Spanish estimate model of construction work units, all of them are traditional methods that can be included in the category of experience-based models of deterministic nature [13]. Nevertheless, these models have been developed and nowadays, among the present most widespread international models, one can find those based on mathematical foundations, ABC methodology and PBC models. These three models are classified in Table **1** according to their degree of detail of the output information, their availability of time and resources and the stage of the building life cycle in which they are mainly developed. Let us make some remarks of each model separately.

1. Models based on mathematical foundations are certainly the ones that have been more developed due to the improvement of the computation techniques. In this regard, there exist distinct estimate models in the construction industry based on probability [14], fuzzy set theory [15] or, especially, on a combination of results on regression analysis, neural networks, genetic algorithms and case reasoning [16-24]. Based on averagesand statistics, we can also include here parametric models [25-28], which determine a rough estimate that makes it possible to define the allocation of costs along the time andto make decisions at an early project stage. It is worth noting, however, that there exists a current trend towards the convergence of different methods that tackle parametric models with greater accuracy [29].

2. Models based on the ABC methodology seem to be the most accurate ones due to the fact that one of the greatest advantages of this methodology is the allocation of all overhead costs to activities that make them necessary. In particular, the principle of applying the ABC methodology in the construction industry is based on the identification and classification of all the activities and operations required to produce each construction work unit, by analyzing in each case all the factors that influence on its cost. The knowledge in advance of these cost factors provides construction companies with an essential tool that they can use to control and manage their economic investment on the building site [30, 31] and to analyze costs and benefits according to the level in which processes are arranged.

   Even if the ABC methodology has been profusely developed in accounting, there is not much research on its use in the international construction industry [32, 33] and this is even more unusual in Spain [34, 35].

3. PBC models are based on the input-output analysis method. In the construction industry, inputs are formed by the required resources and outputs by the products that result after the construction procedure, being the main one the building itself. Due to their capacity of synthesizing the components of the construction system, PBC models consider production processes derived from the scheduling of building works as dynamic cost-generating elements that transform resources into results (see Fig. **1**). It makes possible the subsequent connection among construction estimates and construction planning. In fact, these models are intended to supplement other estimate models by making process information explicit to building actors. In the literature, one can find distinct PBC models that have been devel₂ oped in order to improve project performance and increase levels of sustainability in the construction industry [36-38].

Table 1. Classification of estimate models based on the degree of detail of their output information.

Estimate model	Output Information	Resource and time consumption	Building stage
Mathematical foundations	Conceptual	Low	Pre-design Design
ABC methodology PBC models	Comprehensive	High	Contracting Construction Maintenance Deconstruction

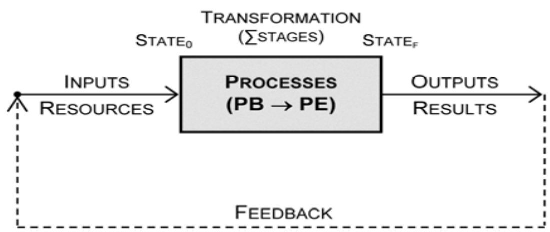

Fig. (1). Building construction system.

The estimate model that we introduce in the current paper agrees with the mentioned principles of ABC methodology and PBC models. Even if it is originally conceived to give an answer to the new demands of the Spanish construction industry, we consider that it can be adapted to the specific requirements of any other construction market, because its main purpose is to reflect the reality of the building construction system and to translate it into costs. Besides, the design and development of the model in the next two sections show that one of the most significant advantages of the model is its transparency, which must play a fundamental role in any construction industry and which is attained in our proposal by eliminating overhead costs and identifying the origin of every single cost derived from the planning, organization and scheduling of building works. This feature avoids cost omissions and repetitions in the estimates, reflecting clearly the configuration of the building site [9]. Framed within comprehensive models, our proposal is particularly suitable for contracting, construction, maintenance and deconstruction stages due to its level of detail and accuracy.

3. DESIGNING THE POP MODEL

The design of any PBC model requires three stages [38]: capturing process cost data, attaching cost data to an object family and creating cost feedback to a design team. In the current section we expose in detail these three stages in case of designing the POP model.

3.1. First Stage: Capturing Process Cost Data

Production processes and, consequently, their costs, derive straightly from the planning, organization and scheduling of works. Before estimating the costs of a building construction, it is essential to plan all these works in a proper way. It implies the identification, classification and characterization of all the production processes involved. As in the rest of PBC models, the first stage in order to design the POP model consists of identifying the production processes that can be distinguished on the building site. This identification allows building actors to control all the costs generated on the building site by providing them with essential and trustworthy information for decision making processes. Depending on their nature, two main different kinds of production processes are identified:

- *Execution processes* (PE)[2]. They represent all the actions related to building construction: from construction processes, directly related to the production of buildings such as laying of building foundation, to logistic works focussed on the management of the building site such as disposal of construction and demolition waste. Safety and quality costs are linked to resources and take part in almost every execution process. The former are essential for tasks to be properly carried out, whereas the latter verify the quality of the processes and hence, they appear all over the estimate, just where they are generated.
- *Basic processes* (PB). They are frontier processes that connect procurement and secondary markets with building sites. These processes result in all the resources that take part in the execution processes such as work force, materials, machinery, tools, energy, waste and information, among others.

3.2. Second Stage: Attaching Cost Data to an Object Family

The second stage to design a PBC model is attaching cost data to an object family. In the case of the POP model, this step consists of designing an Execution Process Classification System and a Basic Process Classification System that make possible to arrange execution and basic processes,respectively, and to codify them with numerical codes that emphasize their international scope.These classifications systems are carried out through the use of two process maps, the executionprocess map (PE map) and the basic process map (PB map), that, according to the principles of the ABC methodology, display required steps and decisions throughout a level framework. In theSpanish construction industry, this proposal enhances considerably the Construction InformationClassification Systems [39, 40] that is currently used, because provides all building actors with acommon language of communication and a greater access to information for competitive decisionmaking.

In both maps the corresponding processes are arranged in four breakdown levels and are labeledwith an identification code. Depending on the map, PE or PB map, the levels are respectively denoted as PE Ln and PB Ln, where n changes from one to four. The first three levels related to each map are defined in their corresponding classification system, but the fourth ones are defined by the construction estimator, by meeting the specific requirements of each building work. In order to illustrate these classification systems, Tables **2** and **3** show, respectively, the first levels, PE L1 and PB L1, of execution and basic processes. Observe that all the basic codes of Table **3** start with an asterisk to make them different from the execution codes.

Execution and basic processes are connected in the process-based estimate. This estimate breaks down the building construction system, which can be considered as a macro execution process of level zero, into four levels of execution processes. In turn, the lowest level of execution processes is divided into basic processes of level four (PB L4) that identify the resources consumed, linking the building site with procurement and secondary markets. All these processes, which reflect the expected reality of building works, are also included in their corresponding maps, whose three upper levels are obtained from their respective classification system. The whole structure of process-based estimates is shown in Table **4** and the sources where the information required can be found.

[2] All the acronyms of the POP model that appear in the current article follow the Spanish abbreviation.

Table 2. First level of the execution processes classification system.

First level of execution processes (PE L1)	
Code	**Process**
01	Building site
02	Previous works
03	Rehabilitation
04	Demolition and dismantling
05	Earthwork
06	Foundation
08	Sanitary sewerage
10	Structure
12	Exterior enclosure
15	Roofing
18	Interior partitions
20	Heating, ventilating and air conditioning
22	Electrical systems
24	Plumbing
26	Gas and liquid systems
28	Fire-suppression systems
30	Electronic safety and security
32	Communication systems
34	Conveying systems
36	Solar systems
38	Waste disposal systems
39	Other facilities
40	Carpentry
45	Paving, surfacing and painting
48	Furnishings
50	Exterior works
60	Final works
65	Maintenance operations
70	Mixed processes
80	Special processes
90	Other processes

Table 3. First level of the basic processes classification system.

First level of basic processes (PB L1)	
Code	**Process**
*00	Human resources
*10	Material resources
*20	Machinery
*30	Ancillary resources
*40	Water and energetic resources
*50	Waste and subproducts
*60	Information resources
*65	Soil
*70	Mixed processes
*80	Special processes
*90	Other processes

Table 4. Structure of process-based estimates.

Breaking down of process-based estimates	
Process	**Source**
PE L0	Whole building construction system
PE L1	PE Classification System
PE L2	PE Classification System
PE L3	PE Classification System
PE L4	Work planning and scheduling
PB L4	Allocation of resources

Once all processes have been identified, classified and placed in the estimate, PE L4 and PB L4 are characterized in individual process records that detail all their comprehensive specifications about technique, safety, quality, cost, environmental and social impacts. Thus, PE L4 records collect all the information about execution processes such as expected results, procedure, actors involved, resources, location, timing, costs and waste [41]. The limits among the different processes must be thoroughly defined in order to avoid omissions or duplications of elements and therefore omissions or duplications of costs in the building estimate [9]. On the other hand, PB L4 records incorporate the characteristics of the resources, their procurement and withdrawal conditions and the generic area where their costs belong according to their function. In total, six generic areas of basic costs have been identified: production, safety, quality, environment, knowledge and administration. Since PB L4 records require the specification of each area, it is being developed a new software [42] that generate partial reports in which costs are related to their corresponding area.

3.3. Third Stage: Creating Cost Feedback to a Design Team

The close connection established among construction scheduling, organization and estimate makespossible the effective planning, management and control of the production processes and their costs during the development of the works. This characteristic provides advantages to the different building contractor departments involved in the construction of buildings in terms of information availability. In particular,

- the Production Department receives comprehensive information of all the tasks required to be implemented and the resources they consume,
- the Purchasing Department gets detailed qualitative and quantitative information about theresources needed for the execution of planned works from the PB map and PB L4 records,
- the Administration Department can address the firm accounting by allocating the invoices to the different PB L4.

All these departments can contribute to the estimate optimization, and, by extension, to the building construction system optimization, what is especially relevant in a period of crisis as the current one, in which efficient management and resource consumption streamlining are essential for buildingcontractors to be competitive. In particular, the mentioned departments can

- make suggestions in order to provide different alternatives to the study that can prevent problems from happening and offer better solutions,
- save time, resources, waste, space consumption and, all in all, costs,
- accomplish the technical, economic, environmental and social objectives stated.

4. COST STRUCTURE

Ramírez-de-Arellano [9] defined costs as the economic effort required to attain a certain objective. In the building construction system, the objective pursued is the construction of the building product and its cost derive from the production processes planned to accomplish it. PBC models allow to estimate the mentioned production costs by converting all the processes involved in the building construction system into costs. Hence, the process-based cost structure is also characterized by its hierarchical, flexible and transparent organization. In this structure, there is room for all costs incurred on the building site, what ensures that efficient estimates can be made. In the case of the POP model, all costs are charged directly from the processes that cause them with their appropriate sign ±, representing costs of positive sign the expenses of implementing the works and costs of negative sign incomes, such as the ones derived from the sale in secondary markets of subproducts obtained on the building site [43].

Fig. (**2**) describes the pyramid cost structure of the POP model. It comprehends two types of cost, basic costs (CB) and execution costs (CE), that are broken down into different levels of detail, according to the principles of the ABC methodology. From the bottom up, CB L4 are the costs of basic processes of level four, which represent the costs of the resources and services from procurement and secondary markets that take part in the execution processes. These costs are strongly influenced by the characteristics of these markets, from where they come or to where they end, respectively, and the corresponding supply or disposal conditions established. Subsequently, execution costs are those related to the execution processes. These costs are obtained by processing the aforementioned basic costs from the lowest level (PE L4) to the highest level (PE L0) of the PE map. This highest level is equivalent to the total production cost without considering external costs such as the building contractor's profit, structural costs of the company or taxes.

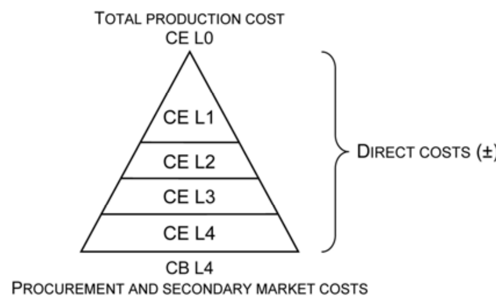

Fig. (2). Cost structure of the POP model.

The POP model is based on simple and repetitive operations that ensure its effectiveness andapplicability.Starting from the consecutive division into processes of the building construction system, the subsequent ascending processing of their costs enables to estimate the total production cost by applying, successively, the following operations:

- *Quantification* (Eq. 1) determines the economic parameters of the production processes of level n:the *quantity of equal units* (Q_u) and their corresponding *unit cost* (C_u Ln).

$$\text{PP Ln}(Q_u, C_u \text{ Ln})^3 \quad (1)$$

In terms of measurement units, execution processes and basic processes of the three first levels, which represent packages of resources of similar nature, are all of them measured in units of process (*u*). On the other hand, those basic processes of the fourth level are measuredin units of the International System of Units (*kg*, *m*, *s*, *u*) and their derivatives (*t*, m^2, m^3, *h*, *mu*).

- *Integration* (Eq. 2) allows to obtain the *complex cost* of a process of level n (C_c Ln) by multiplying its quantity of equal units by their unit cost.

$$C_c \text{ Ln} = Q_u \times C_u \text{ Ln} \quad (2)$$

[3] The acronym PP denotes here the production process that is being considered in the corresponding quantification.

- *Addition* (Eq. 3) is defined as the aggregation of complex costs of a process of level n that enables to obtain the unit costs of upper level processes (C_u L(n-1)).

$$C_u\,L(n-1) = C_c\,Ln \quad (3)$$

The consecutive application of these three operations makes it possible to compute the *total production cost* CE_u L0, starting from the *unit basic costs* of level 4 (CB_u L4) and by processing the different levels of the cost structure.

5. ESTIMATING PROCEDURE

Once the POP model is design and the cost structure is determined, it can be established the exactprocedure to estimate costs in the building construction system, that is to say, it can be explicitlyexposed how to convert production processes into costs. For the identification of the processes thatmake up the building construction system, it is essential to clearly define the objectives pursued, which implies a comprehensive characterization of the building project (reports, specifications and plans), and all factors that can influence the configuration of the works, such as building site characteristics (that is to say, dimension, accessibility and climatology), available resources, expected time, legal framework and roles of the actors involved, among others. Once building construction system requirements and restrictions are known, the planning, organization and scheduling of the works enable the identification and characterization of the production processes in a qualitative and quantitative way. The better the frontiers and interactions among processes are defined, the more accurate description of the system and cost estimate result.

While the division into execution processes of the building construction system is expressed in the PE map, the breakdown into basic processes is collected in the process-based estimate and in the PB map. In process-based estimates, execution processes are coded and broken down from the first level to the fourth one, in such a way that the more specific a process is, the lower level it belongs to. Hence, by dividing progressively the building construction system into more and more specific processes the PE map, first, and the estimate, later, are drawn up. The total building production cost can then be obtained by repeatedly applying the operations of quantification, integration and addition of costs, that we have defined in the previous section, from the lower level of basic costs (CB L4) to the highest level of execution costs (CE L0 (Eq. 4)), which represents the cost of the whole building construction system. That is to say,

$$CE\,L0 = \textstyle\sum_{c,n} C_c\,Ln = \sum_{u,n}(Q_u \times C_u\,Ln) \quad (4)$$

where recall that

- CE L0 is the total production cost,
- C_c Ln is the complex cost of a productive process of level *n*,
- Q_u is the number of equal units of process,
- C_u Ln is the unit cost of a productive process of level *n*.

Thereby, process-based estimates start from the quantification (Eq. 5) of PB L4, which concentrate the economic information of the resources and services that are going to take part on the execution processes, directly related with procurement and secondary markets.

$$PB\,L4(Q_u, CB_u\,L4) \quad (5)$$

The integration (Eq. 6) and subsequent addition (Eq. 7) of CB L4 generate the unit costs of CE L4, placed at the lowest level of the PE map, which represent the costs of the actions that are going to be undertaken on the building site.

$$CB_c\,L4 = Q_u \times CB_u\,L4 \quad (6)$$

$$CE_u\,L4 = \textstyle\sum_c CB_c\,L4 \quad (7)$$

In the same way, the unit costs of CE L3 are obtained by the quantification (Eq. 8), integration (Eq. 9) and addition of CE L4 (Eq. 10).

$$PE\,L4(Q_u, CE_u\,L4) \quad (8)$$

$$CE_c\,L4 = Q_u \times CE_u\,L4 \quad (9)$$

$$CE_u\,L3 = \textstyle\sum_c CE_c\,L4 \quad (10)$$

Successively, the quantification (Eq. 11), integration (Eq. 12) and addition (Eq. 13) of the costs of the execution processes CE L3, CE L2 and CE L1 make possible to obtain the unit costs of their upper execution processes until reaching the top of the system structure (CE L0) which represents the total production cost (Eq. 14).

$$PE\,Ln(Q_u, CE_u Ln),\ \text{for all}\ n \in \{3,2,1\} \quad (11)$$

$$CE_c\,Ln = Q_u \times CE_u\,Ln,\ \text{for all}\ n \in \{3,2,1\} \quad (12)$$

$$CE_u\,L(n-1) = \textstyle\sum_c CE_c\,Ln,\ \text{for all}\ n \in \{3,2,1\} \quad (13)$$

$$PE\,L0(1, CE_u\,L0) \quad (14)$$

All this data are collected on the process-based estimate, which is a document that comprisesseven columns (see the examples exposed in Tables **5** and **6**). The first three columns identifyeach process that takes part in the estimate by its code, measurement unit and name. The next three columns supply information about the economic parameters (Q_u, C_u and C_c) of the processesinvolved. Finally, the last column weighs all complex execution costs by ascribing them a percentage over the total production cost. This percentage provides information that enables building actors togive priority to the optimization and control of those processes that accumulate major percentages.

Additionally, the process-based estimate is completed with records of PE L4 and PB L4, in which specifications of these processes are detailed. PE L4 records collect information about what is needed to be done, where, when, how, under whom responsibility and with what resources. PB L4 records compile information about the properties of the resources that take part in the execution processes. From all this extensive information, many types of reports can be obtained such asreports that identify where all the resources are used, by indicating in which PE L4 is every PB L4 applied.

We finish our presentation of the POP model by indicating that this model does not only make possible the creation of estimates close to the reality of building works, but also enables cost optimization by comparing different hypotheses of planning, organization and scheduling. In economic terms, the optimum estimate can be defined as the one that

Table 5. Estimate of the structure process of a real residential building construction (Elaborated by the technical architect R. Villar).

Process-based estimate of a residential building structure						
Code	**UNIT**	**Process**	Q_U	C_U	C_C	**%**
10	*u*	**Structure**	**1.00**	**32,935.33**	**32,935.33**	**100.00**
1000	*u*	**In situ concrete**	**1.00**	**3,566.73**	**3,566.73**	**10.83**
100020	*u*	**Piers**	**1.00**	**3,566.73**	**3,566.73**	**10.83**
1000200005	*u*	Construction of ground-floor piers	1.00	1,893.61	1,893.61	5.75
*1005150140	*m*3	Reinforced concrete 25 N/mm^2	4.15	54.60	226.59	
*7010000005	*m*2	Labour force and complementary materials	47.62	24.00	1,142.88	
*7010100100	*kg*	Steel fabrication and laying	524.14	1.00	524.14	
1000200015	*u*	Construction of upper-floor piers	1.00	1,673.12	1,673.12	5.08
*1005150140	*m*3	Reinforced concrete 25 N/mm^2	3.58	54.60	195.60	
*7010000005	*m*2	Labour force and complementary materials	37.76	24.00	906.24	
*7010100100	*kg*	Steel fabrication and laying	571.29	1.00	571.29	
1030	*u*	**Horizontal and sloping frameworks**	**1.00**	**29,368.60**	**29,368.60**	**89.17**
103005	*u*	**Concrete slabs with continuous shuttering**	**1.00**	**29,368.60**	**29,368.60**	**89.17**
1030050005	*u*	Construction of ground-floor waffle slab	1.00	6,473.21	6,473.21	19.65
*1005000050	*m*2	Welded wire mesh B 500 S 15 × 15 × 5*cm*	171.06	1.20	205.27	
*1005050100	*u*	Breeze block for waffle slab	535.50	0.50	267.75	
*1005150140	*m*3	Reinforced concrete 25 N/mm^2	32.10	54.60	1,752.77	
*7010000005	*m*2	Labour force and complementary materials	113.33	24.00	2,719.99	
*7010100100	*kg*	Steel fabrication and laying	1,527.43	1.00	1,527.43	
1030050020	*u*	Construction of first-floor waffle slab and stairs	1.00	13,266.48	13,266.48	40.28
*1005000050	*m*2	Welded wire mesh B 500 S 15 × 15 × 5*cm*	269.40	1.20	323.28	
*1005050100	*u*	Breeze block for waffle slab	843.33	0.50	421.67	
*1005150140	*m*3	Reinforced concrete 25 N/mm^2	55.36	54.60	3,022.49	
*7010000005	*m*2	Labour force and complementary materials	190.49	24.00	4,571.86	
*7010100100	*kg*	Steel fabrication and laying	4,927.18	1.00	4,927.18	
1030050040	*u*	Construction of roof waffle slab	1.00	9,628.92	9,628.92	29.24
*1005000050	*m*2	Welded wire mesh B 500 S 15 × 15 × 5*cm*	228.00	1.20	273.60	
*1005050100	*u*	Breeze block for waffle slab	713.73	0.50	356.87	
*1005150140	*m*3	Reinforced concrete 25 N/mm^2	42.79	54.60	2,336.12	
*7010000005	*m*2	Labour force and complementary materials	158.61	24.00	3,806.57	
*7010100100	*kg*	Steel fabrication and laying	2,855.77	1.00	2,855.77	

increases the efficiency of the building construction system by minimizing production costs without compromising the expected results. From the simulation of different planning alternatives, different process-based estimates can be elaborated and hence the optimum estimate chosen.

6. CASE STUDY: APPLICATION TO STRUCTURAL COSTS ESTIMATING

In this section, the POP model is implemented in a real residential building construction with the peculiarity that it continues a previous construction that was brought to a

Table 6. Quantification of resources of the PE of construction of ground-floor piers (Elaborated by the technical architect R. Villar).

Quantification of basic processes of residential building construction							
Process identification	Data				Results		
	n	X	Y	Z	Aux.	Partial	Total
10 u Structures							
1000200005 *u* Construction of ground-floor piers							
*1005150140 m^3 Reinforced concrete 25 N/mm^2							4.15
Dwellings 45 to 48	1.03				4.03	4.15	
Piers 10, 14, 19, 23, 28 and 32 Piers 11, 12, 13, 20, 21, 22, 29, 30 and 31 *7010000005 m^2 Labour force and complementary materials	6.00 9.00	0.25 0.25	0.35 0.35	2.65 3.35	1.39 2.64		47.62
Dwellings 45 to 48	1.00			0.20	238.12	47.62	
First-floor waffle slab *7010100100 kg Steel fabrication and laying	4.00 4.00 4.00	2.03 6.25 3.57	1.11 8.85 0.55	m^2 / m^2	9.01 221.25 7.85		524.14
Dwellings 45 to 48		*bars*		*kg / m*			
Diameter 20 *mm*	1.00			2.46	4.00	9.84	
Pier 11	1.00	4.00	4.45		4.00		
Diameter 16 *mm*	1.00			1.58	243.40	384.57	
Piers 10 and 23 Pier 11 Piers 12 and 21 Pier 13 Piers 14 and 19 Pier 20 Pier 22 Piers 29, 30 and 31	2.00 1.00 2.00 1.00 2.00 1.00 1.00 3.00	4.00 2.00 4.00 6.00 6.00 6.00 6.00 4.00	3.59 4.29 4.29 4.29 3.59 4.29 4.29 4.29		28.72 8.58 34.32 25.74 43.08 25.74 25.74 51.48		
Diameter 12 *mm*	1.00			0.89	60.48	53.83	
Piers 12 and 21 Pier 13 Pier 20 Piers 28 and 32	2.00 1.00 1.00 2.00	2.00 2.00 2.00 4.00	4.13 4.13 4.13 3.43		16.52 8.26 8.26 27.44		
Diameter 6 *mm*	1.00			0.22	345.00	75.90	
Pier stirrups 10, 14, 19, 23, 28 and 32 Pier stirrups 11, 12, 13, 20, 21, 22, 29, 30 and 31	6.00 9.00	26.00 21.00	1.06 1.06		156.00 189.00		

standstill during the structure phase as a consequence of the financial crisis of their former building actors. It is important to remark that traditional estimate models do not work properly in this type of singular constructions, because they are not standardized activities.

Specifically, it is required to estimate the costs of the execution of *u* structures of the first level of the Execution Process Classification System, all of them being of the same type, labeled with the code 10. In the design of the corresponding POP model, the level PE L1 is broken down into processes of the second, third and fourth levels that represent all the activities to be undertaken at the building site to erect these structures. In turn, the lowest PE level (PE L4) is divided into PB L4, which represents the resources that take part in the execution processes identified. All these activities derive from the planning, organization and scheduling of the structure works.

The first three columns of Table **5** show the extended PE map under study, which classifies and codifies PE L1, PE L2, PE L3, PE L4 and PB L4. The three upper levels of the PE map are stated in the Execution Process Classification System and the two lower ones are specifically defined for this building construction. On the other hand, the four columns of the left side collect the economic parameters of each process: quantity (Q_u), unit cost (C_u), complex cost (C_c) andoverall percentage (%). The total structure production cost can be obtained after a consecutive application of the operations of quantification, integration and addition of costs from the lower level of basic costs (CB L4), to the highest level of execution costs (CE L1), which represents the total cost of the structure execution process.

The quantities of the basic processes are calculated in their corresponding measurement units in the quantification form. This form details the resources consumed by each execution process of level 4 (PE L4). Table **6** shows an example of quantification form.

CONCLUSION AND FUTURE RESEARCH WORKS

Derived from the principles of the ABC methodology and in tune with the innovative PBC approach, we have introduced in the current paper the POP model, a new comprehensive estimate model for the construction industry that

- eliminates overhead costs,
- identifies the origin of every single cost derived from the planning, organization and scheduling of building works,
- incorporates as direct costs all types of costs from building sites with their corresponding sign (±),
- focuses on processes rather than on resources,
- designs a Production Process Classification System, by considering separately execution and basic process maps,
- makes possible the visibility and verification of all the information provided and the reflection of the real configuration of each building site,
- can be adapted to the construction industry evolution.

It is worth noting that the POP model is currently being applied by experienced practitioners of the Spanish construction industry to different types of real construction works such as restoration, premises refurbishment and new residential construction [41, 44, 45, 46]. Its implementation has proved its capacity to collect and manage, in an organized and coherent way, all the information required to estimate all the costs expected on the construction site, without omissions and repetitions. Practitioners who have been involved in the experimentation of the model have highlighted the transparency and accuracy of the model, which makes it possible to reduce the inherent uncertainty of construction estimates. In this regard, it is known that the quality and accuracy of any estimate model is ensured by the importance of expert knowledge [12, 47]. Such is the case of the POP model, whose accurate implementation requires well-defined projects and a rigorous planning and definition of the frontiers among processes in order to check that all construction costs have been considered in the right place. In fact, the profile of the main user of the model is that of a building contractor

- with expert knowledge on construction management,
- awarded with the construction of a building,
- with access to all the incoming information required,
- who can take advantage of the enormous output information during the development of construction works.

Even if the POP model has originally been conceived for the Spanish construction industry, it can be adapted to the specific requirements of any other construction market. It is due to the fact that this model is essentially based on the identification of the origin of every single cost derived from the planning, organization and scheduling of building works. Hence, a thoroughly analysis of these costs in the new market would make feasible the application of the method. Besides, the flexibility of the classification system that the POP model designs

- makes possible the organization and standardization at an international level of the structure 29 of the process-based estimates,
- provides building actors with a common language of communication and a greater access to 31 information for competitive decision-making,
- ensures its usefulness for all types of worldwide construction works, such as new construction, demolition, rehabilitation and urbanization works.

As a consequence, we consider that a future research line developed with the cooperation of international teams of other construction markets in order to determine how to adapt in a coherent way the POP model to these markets is not only interesting, but also profitable to the consolidation of the method.

Apart from this possible internationalization of the model, other future research lines to be dealt with are focused on the further implementation of the POP model in different types of construction works such as business premises refurbishment [46] and the design of a comprehensive process-based building construction management model including quality and cost control [41, 45, 48]. Besides, this model can be extrapolated to a comprehensive process-based construction management model in which not only costs are measured, but also other indicators like the environmental impact, the safety level of construction works or the monitoring and controlling of all dimensions of sustainability.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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