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CONSTRUCTION COST ESTIMATES FOR RESIDENCES IN SPAIN: practical application of the Pcr.5n model

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Abstract. The construction cost estimation systems in Spain are undeveloped and, hence, infrequently used by technicians and professionals in the building sector. However, estimation of an approximate real cost prior to the execution of the work is compulsory under current legal regulations (Technical Building Code). Therefore, the development of research projects on construction cost estimation models such as the one described and demonstrated in this talk is extremely interesting.

The objectives of the present research are to establish a construction cost estimation system for the residential building sphere in Spain, and to demonstrate the practical application of a quick and precise model for estimating the construction costs by contract.

This model is referred to as Pcr.5n (Cost estimation with 5 levels of process design it makes it possible to formulate a cost estimate that is implemented in the stages prior to the conceptualization of the architectural project, namely during the process of carrying out preliminary studies, drafting and the basic project.

At each level of calculation, the model adjusts the estimate in accordance with how the definition of the project advances (successive approximations at finite intervals). The final objective and hypothesis of the model is the achievement of at least 90% accuracy with regard to the final cost estimation of the work.

The cost calculation for material execution is structured using functional three-dimensional cubic parameters for the planned space, and constructive two-dimensional metric parameters for the surface that envelopes around the facade and the building's footprint on the plot of land. These functional and constructive parameters are considered in each stage of the calculation process along with other thematic/specific parameters having to do with the management, design and execution of the exact building project, the cost of which has been estimated for the planned works, according to contract.

Keywords:Building, cost, estimation, housing, model, project.

I. HISTORIC PRECEDENTS

In the introduction to his "Ten Books on Architecture", Vitruvius Polion (Vitruvio, 1787), makes reference to an old law stipulating that the architect is obliged to calculate the "true estimate" of a project's final cost. Once the budget had been accepted and approved, all of the architect's properties were mortgaged by the government administration behind the project in question, until its ultimate financial settlement.

If the work was settled with a cost increase that did not exceed "*more than a quarter part*" of the approved budget, it was paid for using public funds, and the architect was not "*...subject to any penalty*". But if the project's final cost exceeded the original estimate by more than a quarter part, this excess was defrayed with the architect's own mortgaged property. When the originally approved financial forecasts had been met, the architect's property was released from the mortgage and he received fees in recognition of this fact.

This demonstrates that in 1 BC, there was already awareness about methods of final cost estimation for building projects, with penalties in effect for architects that strayed from financial previsions by more than 25% over the initial cost estimate for the construction project.

II. PLANNED OBJECTIVES AND FORMULATED HYPOTHESES

The research has two basic goals. On the one hand, to describe the current situation in Spain with regard to construction cost estimation techniques for residences, and on the other, to explain the concept of the Pcr.5n cost estimation model for architectural projects using preliminary studies of the project to be executed.

The goal is to obtain a useful working tool for students, technicians and professionals in the building sector that enables the calculation of the actual cost of the planned work, and to demonstrate with a simple practical application a reasonable and feasible technical calculation that is easy to use.

The objective focuses on achieving a reasonable level of precision in the estimation of final construction costs for a project, insuring that the deviations remain below the 10% permitted by the EU with regard to the project's initially approved budget. This deviation can also be considered the maximum in terms of what is reasonable from a perspective of financial security and the initial viability of the development, both on a public and private level. Thus, by applying the developed model, the objective is to obtain deviations of less than 10% of the actual cost of the finished work. These deviations will be measured at the following intervals, arranged from lowest to highest in terms of the project's level of definition: at level 1, initial development valuation (+/- 25%, a quarter part according to Vitruvius' *Ten Books*); at level 2, corresponding to preliminary studies (+/- 20%, maximum margin of error allowed by Law 3/2011 on Contracts for the Spanish Public Sector); at level 3, drafting (+/- 15% of the admissible maximum margin of error); and at levels 4 and 5, corresponding to the basic project, deviations of less than 10%. This is the legally allowed percentage for the financial acceptance of the work through an increment in the project's final mediation, with respect to the initial mediation state of the executed project.

Therefore, the calculation stages or levels contemplated in the Pcr.5m model, prior to the execution stage of the project are:

1. Initial development: Construction costs calculation based on initial sale price
2. Preliminary studies: Estimation of construction costs based on total cubic meters
3. Drafting: Estimation of construction costs based on the external envelope, the interior volume and the footprint on the ground
4. Basic Project: Estimation of construction costs based on square meters built, with wheighted average parameters of management, project and development
5. Basic development: Costs construction calculation based on basic sale price

Figure 1 shows the trend in percentage of deviation of costs estimates from the initial stages nr. 1 (10% deviation) to the Basic development nr. 5 (5% deviation)

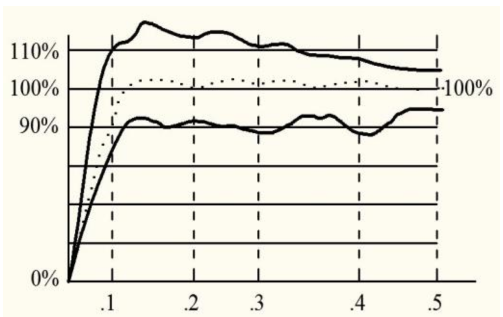

Figure 1. Estimated calculation process by level

Source: the authors

The purpose of these objectives is to provide a positive response to four hypotheses, formulated as follows:

1. The first hypothesis is based on the fact that estimated cost calculations for residential architectural projects result in maximum deviations of 10% over the project's final cost, which is to say, half of the maximum margin of error permitted by Law 3/2011, Law of Contracts for the Public Sector, in which articles 311 and 312 stipulate that the maximum deviation is 20%, in order to ensure that the planning technician is not subject to penalties over the actual construction cost.

2. The second hypothesis asks that, in addition to being accurate, the model in development must be fast, with easy practical application. This supports the objective of introducing it into everyday construction cost estimates in the building sector of our country, through the approximate calculation based on two-dimensional (m2) and three-dimensional parameters (M3), which is a common approach in countries such Germany (BKI, 2012), United States (Cox & William, 1996) and Australia (Cheung, 2005).

3. The third hypothesis intends that the model go beyond the methodology that is usually found in cost estimation methods, which are based on an estimation of costs per square meter. To this end, the proposed cost estimation model is structured around building systems and functional spaces, costs that are gradually defined and estimated during the design process (successive approximations at finite intervals).

4. The fourth hypothesis is that history supports this model, both in its conceptual origins and in its methodological development: Vitruvius (beauty + utility + solidity) versus the Pcr Model: (exterior envelope + interior space + foundation footprint).

III. STATE OF THE MATTER: COST ESTIMATION IN SPAIN

In Spain there have been very few treatises published on construction cost estimation. Only two (Paricio, 1971) and (Carvajal, 1992) have explored this issue in-depth. Additionally, there are only two commercial construction cost estimation programs available in the Spanish market, Presto (Soft) and Arquímedes (Cype).

However, the current Technical Building Laws stipulate that the basic project include at least one approximate budget by chapter (Anejo I.2.V). This budgetary estimation should be calculated using cost estimation models, since this planning stage does not include detailed documents or highly developed plans that correspond to the executed project. Therefore, the need exists for the specification and development of construction cost estimation models.

IV. RESEARCH METHODOLOGY

The methodology used to obtain the intended results for the development of the Pcr.5n model and to respond to the established hypotheses, has been structured into the three following stages:

1st Stage: INTRODUCTION

During this initial phase, the origin and justification of the research is set out, based on the requirements stipulated by current legislation on construction cost estimation and its possible penalties when deviations occur in the actual costs of the work in question.

The proposed objectives and formulated hypothesis are specified and designed, as well as the advisability and advantages of the developed cost estimation model.

2nd Stage: ANALYSIS. EVALUATION

This second phase involves the development of the internal calculations made using traditional analytical methodology on projects and real building costs (Pina, 1989, 1991 and 2004), thereby obtaining the minimal functional unit costs (half-bath, bedroom, kitchen, washroom, living room), the costs of the building systems for the exterior envelopes (roof and facades), and the cost of the building's footprint on the plot of land (preparation of the land, foundation, basements). Also, an estimate is made of the percentages by which management, planning and construction parameters increase the calculated cost of the planned work, beyond the contractor's general costs and profits.

As a result of the research have been obtained with statistics costs performed by the software SPSS (Statistical Package of the Social Sciences) (Figure 2).

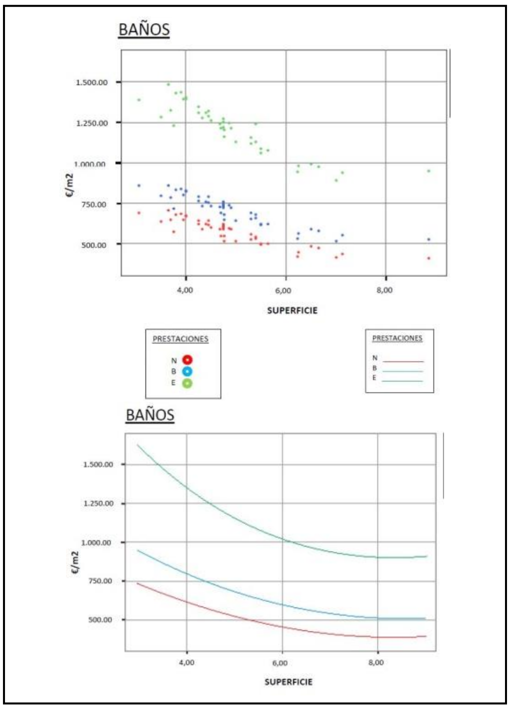

Figure 2. Analytical cost/surface area calculations in use (SPSS)

Source: the authors

Finally, the internal, theoretical results of the model are analyzed through information that is structured using tables which make it possible to contrast and validate these results against the external calculations and evaluations of the actual final construction costs.

Subsequently, the external analysis and evaluation of the Pcr.5n model (Estimation of reference costs using 5 calculation levels) is carried out, and the theoretical model is applied to 240 completed building projects, whose real and final construction costs are known. This contrasting and evaluation process makes it possible to reconcile the results and definitively validate compliance with the four original hypotheses:

(1) Errors / deviations less than 10% over the final construction cost.

(2) A model that is fast with an easy practical application.

(3) Spatial / volumetric calculations (from 2D to 3D).

(4) (Beauty + utility + solidity) versus (exterior envelope + interior space + foundation footprint).

Finally, this stage involves the synthesizing of the theoretical and practical conclusions.

In summary, the methodology developed for the current research project has centered on the theoretical and practical development of the synthetic calculation procedure, in order to achieve compliance with the four hypotheses detailed in items (1), (2), (3) and (4), above.

And lastly, the Pcr.5n model incorporates and integrates the commonly applied methods in our country that are based on specifications for constructed surface areas by floor, the cubic method for constructed volume, and the "Storey" box method that takes into account floors and facades and their corresponding heights (Cheung, 2005). This results in an integrated model with fewer errors and deviations than those results obtained using the independent application of the aforementioned methods.

Figure 3 graphically displays the five levels of calculation developed by the Pcr.5n model.

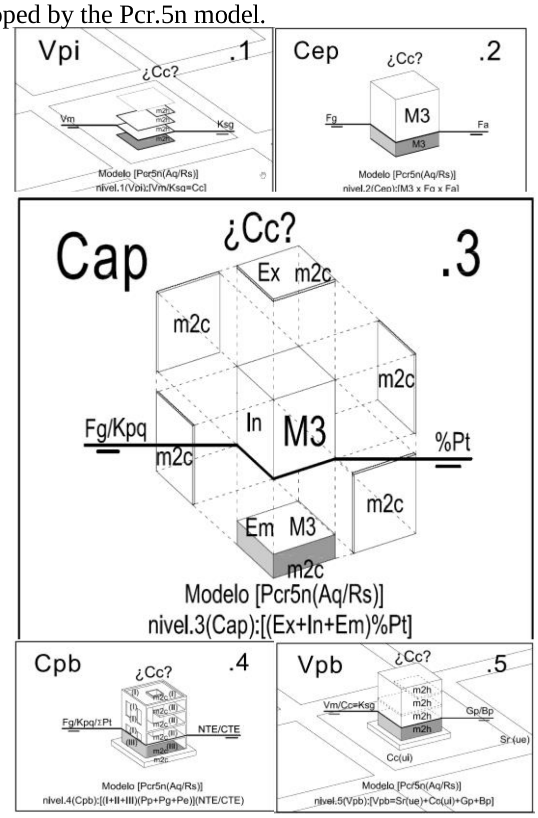

Figure 3. – General cost estimation model.

Figure 4 shows one of the 240 factsheets type of the projects database. The zoomed area includes the detailed data of the project. The dawn part and the upper right includes the two-dimensional and three-dimensional graphics references.

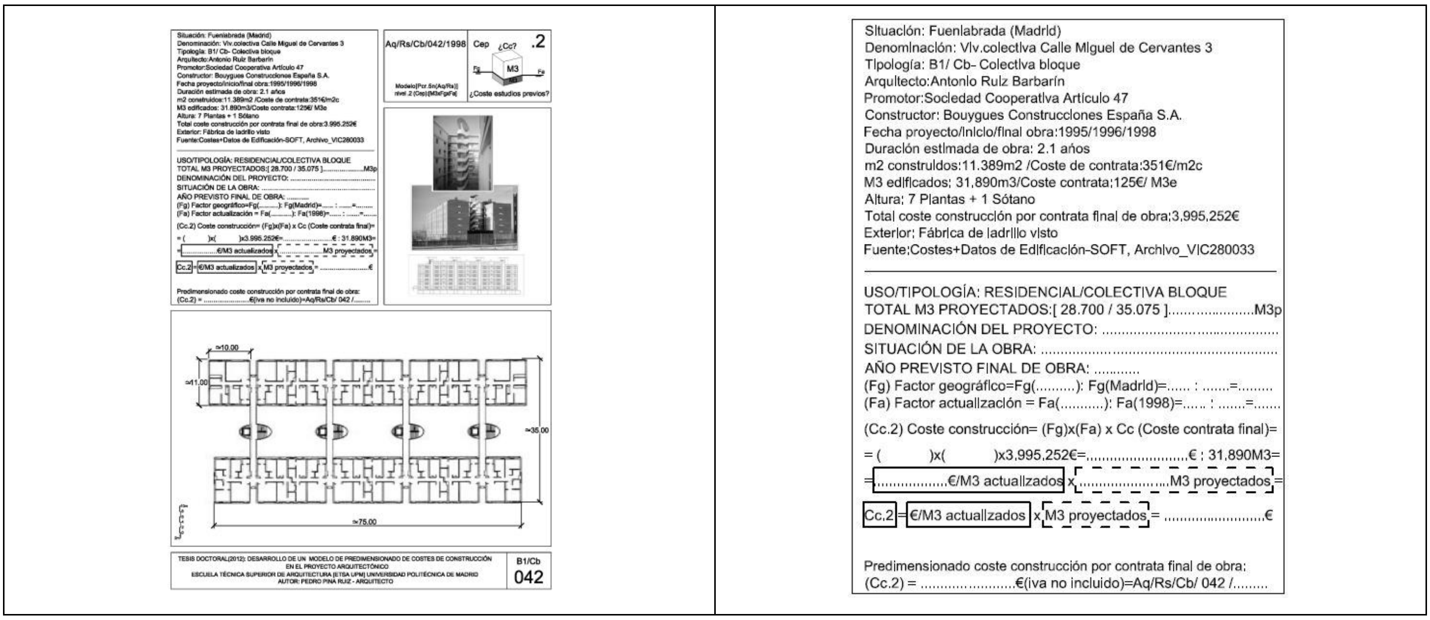

Figure 4. type of data sheet found in the Pcr.5n model database.

Source: the authors.

Figure 5 shows the apartment building of 159 units whose costs construction and percentage deviations are estimated.

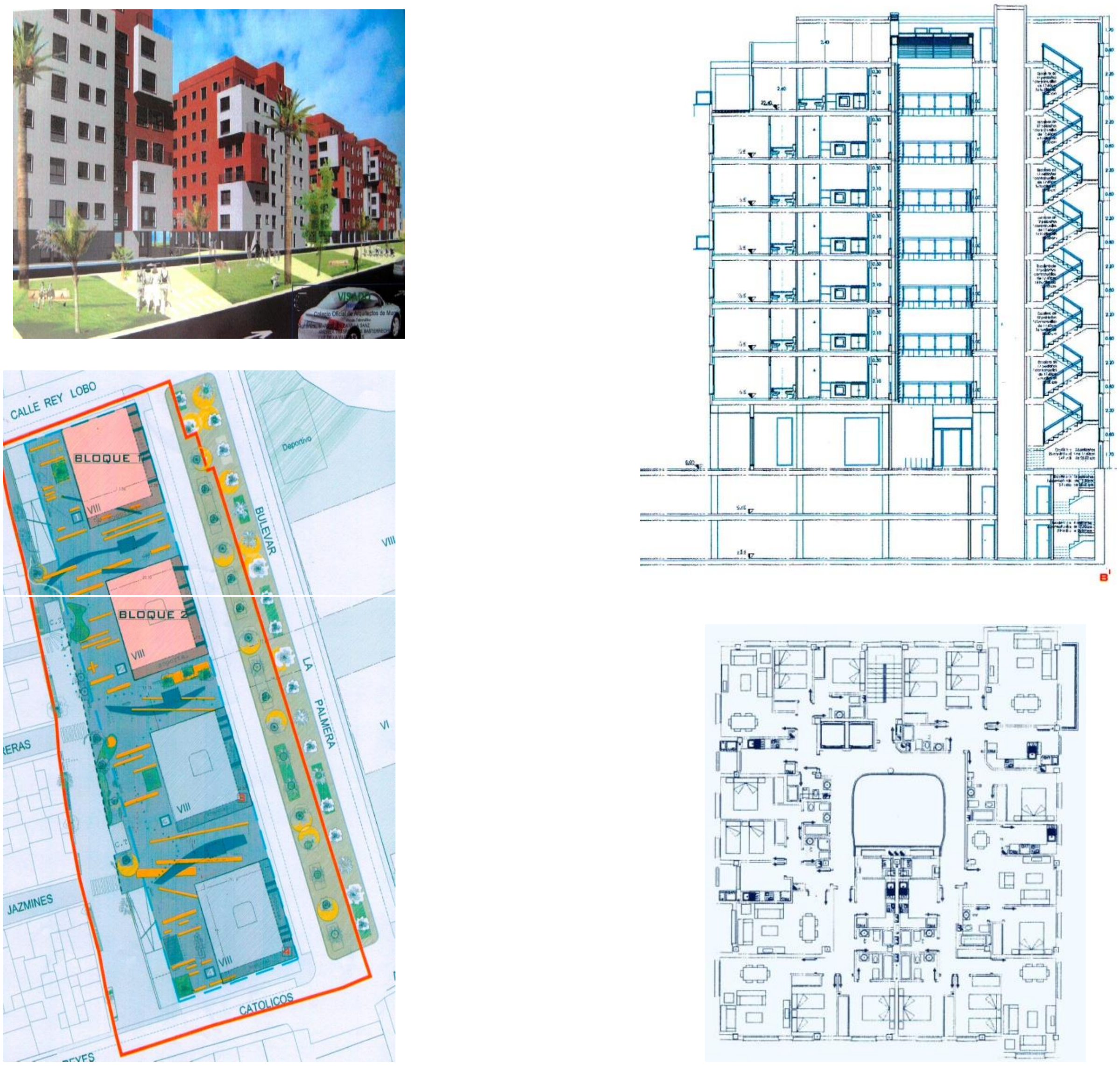

Figure 5. **Figure 5**: Perspective, floor plans and sections of 159 residences, retail spaces, parking garages and storage units

Source: Mariano y Luz de la Villa-Arquitectos- Murcia - Spain

V. DATA ANALISIS, DISCUSSION AND SUMMARY OF RESULTS

For an example of the practical application of the specified model, we chose a project consisting of 159 residences, retail spaces, parking garages and storage units in Murcia (Spain).

The project consists of four blocks of community housing with a square floor plan, that are each 8 stories high with 2 basement garages.

Table 1, contains a selection of 12 projects excerpted from the Pcr.5n model database, which were selected using criteria related to the volume of the construction and its overall typology.

The sample size is sufficiently representative for the cost estimation of a similar project (BKI, 2012).

TABLE I. SELECTED PROJECTS FROM THE OF THE PCR.5N MODEL DATABASE (COLLECTIVE HOUSING/B1CB: 159 RESIDENCES)

Code number	Designation	Location	Year construction finalized	Contracted cost	m2	M3	Cost €/m2	Cost €/M3
B1/Cb/027	56 Subsidized housing	Madrid	1993	1.952.154	7.305	21.501	267	91
B1/Cb/031	Collective housing	Malaga	1998	2.339.259	8.242	22.686	284	103
B1/Cb/034	53 Subsidized housing	Madrid	2003	3.409.352	8.497	26.004	401	131
B1/Cb/035	85 Subsidized housing	Murcia	1987	1.878.808	9.000	27.000	209	70
B1/Cb/041	**128 Residences √**	Madrid	2003	3.847.334	10.492	31.476	**367**	**122 √**
B1/Cb/042	**Collective housing √**	Madrid	1998	3.995.252	11.389	31.890	**351**	**125 √**
B1/Cb/054	**96 Subsidized housing √**	S.Sebastian	2001	5.080.000	13.116	44.980	**387**	**113 √**
B1/Cb/060	**155 Residences √**	Madrid	1995	5.629.053	18.847	55.081	**299**	**102 √**
B1/Cb/062	45+48 Residences	Madrid	2000	4.640.414	15.308	58.407	303	79
B1/Cb/063	**Building with 174 Residences√**	Seville	2002	7.283.420	21.479	62.431	**339**	**117 √**
B1/Cb/064	**168 Subsidized housing √**	Vitoria	2002	7.420.037	23.086	67.345	**321**	**99 √**
B1/Cb/067	156 Residences for young people	Madrid	2007	12.187.375	28.237	75.500	432	161

Source: the authors

Table 2 depicts a selection of six projects that are comparable to the project being evaluated, with specific design-type criteria and similar in features and quality to the group of planned projects. This criteria (graphically displayed on figure 6) is supported by the Spanish Order/805/2003 ECO, regarding the rules for valuing real estate assets and which defines the fees for certain financial purposes. We obtain certain average unitary costs of 548€/m2 and **189 €/m3** (2013) weighting the cost per square meter (€/m2c) and cubic meter (€/M3e) to a restatement factor (Fa) and to a geographical factor (Fg).

TABLE II. CONTROL/COMPARABLE SIMILARITIES TO THE PLANNED PROJECT (COLLECTIVE HOUSING/B1/CB: 159 RESIDENCES)

Code number	Designation	Location	Cost €/m2c	Cost €/M3e	Fa 2013/…..	Fg Murcia/……	Cost 2013 €/m2	**Cost 2013 €/M3**
B1/Cb/041	**128 Residences √**	Madrid	**367**	**122**	172/115	100/112	**488**	**162 √**
B1/Cb/042	**Collective housing √**	Madrid	**351**	**125**	172/86	100/112	**625**	**222 √**
B1/Cb/054	96 Subsidized housing	S.Sebastian	387	113	172/104	100/110	580	169
B1/Cb/060	155 Residences	Madrid	299	102	172/75	100/112	610	208
B1/Cb/063	**Building with 174 Residences√**	Seville	**339**	**117**	172/108	100/101	**532**	**184 √**
B1/Cb/064	168 Subsidized housing	Vitoria	321	99	172/108	100/110	465	144
B1/Cb/XXX	**159 Residences (2013)**	Murcia	………………………………………...				**548**	**189**

Source: the authors

Table 3 contains specific calculations for the planned building of 159 residences, retail spaces, parking garages and storage units, along with the five calculation levels of the Pcr.5n model, numerically developing the formulas and concepts summarized in Figure 4, as described below:

Stage 1. At this first level of the initial development, construction costs are calculated by multiplying the homogenized surface area by the selling price per square metre of the finished building divided by the coefficient (Ksg), whose value is a function of the cost of the land and the costs and benefits of the construction company.
Stage 2. At this second initial study level, the construction costs are calculated by multiplying the mean unitary cost per cubic metre of projects of similar characteristics by the cubic metres projected.
Stage 3. In this third level of the draft project, the construction costs are estimated by the product of the georeferenced material cost of construction (Cg), comprising the roof, façade, interior volume and "footprint" of the building (all increased by the thematic parameter (Pt) which takes into consideration general costs and the benefits of the construction company.
Stage 4. At this fourth level of the basic project estimation, basic plans and specifications are already available, and the predimensioning of the construction cost can be broken down into three chapters: (I) roof and façade, (II) interior functional uses and (III) foundations and basements. The result of the above calculation is then weighted by the parameters management, project and execution (Pg + Pp + Pe), which provides the closed estimate of the projected work.
Stage 5. At this level, the calculation is based on the selling value minus the cost of the land, promotion costs and benefits of the construction company, giving the construction costs of the project as "remainder".

The results represent construction costs with a deviation range of [4.79% - 9.52%] over the actual costs. This error is less than the 10% maximum that was originally proposed as the objective and hypothesis of this study.

Table 3 reveals that the further one advances through the model's calculation levels, the better the approximation of the estimated value to the real and final cost of the planned construction. In short, Level 1 (market evaluation of the initial project) provides a greater deviation than Level 5 (market evaluation of the basic project) [+ 6.93 compared with + 4.79 %). Level 2 (Construction costs in previous study phase) gives a higher deviation than the subsequent phases of calculating construction costs, Level 3 (pre-project) and Level 4 (basic project) [+ 9.52 % compared with + 6.55 % and + 5.46 %, respectively] .

TABLE III. COST ESTIMATES PLANNED BUILDING (B1/CB/XXX:159 RESIDENCES) AND CALCULATION OF DEVIATION % OVER REAL COST

Calcu-lation level	REAL FINAL COST (2013) OF BUILDING B1/Cb/XXX=159 Residences (Murcia/Spain: 13.609.803€) CALCULATIONS FOR ESTIMATING CONSTRUCTION COSTS BY CONTRACT (without taxes)	% error deviation
	Stage 1: Valuation of initial development (Vpi): [Cc= Vm/Ksg] Total constructed surface area = 24.310m2 Homogenized surface area of "entire residence" =(433 m2.Ex1,214)+ +(13.861 m2Vx1,000)+ (1.098 m2.Lx0,435) + +(8.214 m2.Gx0,565)+(704 m2.Tx0,649)= Sh=19.974 m2h.V **Cc.1** = Cc.0 x Sh = Vm/Ksg x m2h.V = 2.550€/m2c : 3,50 x 19.974 = **14.552.486 €**	**+6,93%**
	Stage 2: Preliminary cost studies (Cep): [M3xFgxFa] Total projected volume= 78.865M3e; €/M3e (2013)= **189 €/M3** updated (Table 2) **Cc.2** = €/M3 real x M3e projected = 189€/M3 real x 78.865 M3 projected **14.905.485 €**	**+9,52%**
	Stage 3: Drafting cost (Cap): [(Ex + In +Em)%Pt] Cg = Cost material execution x F location **Cc.3** = (Cg) Cost M.E. location + 23%Pt specific parameter = [(1.976m2Q x 172€/m2Q)+ +(10.852m2Fx152€/m2F) + (8 UdA x 36.600€/UdA) + (1.461M3E x 134€/M3E) + (45.741M3V x 134€/M3V) + +(4.941M3L x 58€/M3L) + (2.112M3T x 87€/M3T) + (24.642M3G x 76€/M3G) + (8.661m2H x 119€/m2H)] x x[Fg = Murcia = 1,000] + [23% over (Cg)] = Cc.3 = **14.733.913€**	**+6,55%**
	Stage 4: Cost basic project (Cpb): [(I+II+III)x(Pg+Pp+Pe)] (NTE/CTE) Cc.4 = (Cg) Cost M.E. location + (€Pt) specific parameter € = [(I) Exterior + (II) Interior + + (III) Built-in] x [Fg] x [Pg + Pp + Pe] **(I) Exterior** = [(1.976 m2Q x 172 €/m2Q) + (8.580 m2 Fm x 110€m2 Fm) + (2.262m2 Fh x 365 €/m2Fh)]= = 2.109.302€ EXTERIOR **(II) Interior** = [(8 UdA x 27.200€/UdA) + (443m2 x E x 420 €/m2E) +(620m2 B_1 x 1.495 €m2B_1) + (803m2 B_2 x x 1.346 €m2B_2) +(1.515m2Cx 592€/m2C) + (1.604m2V x 506€/m2V) + (461m2L x 413€/m2L) + +(2.120m2D_1 x 357 €/m2D_1) + (2.450m2D_2 x 319€/m2D_2) + (4.287m2S x 295 €/m2S) + (1.098m2L x 159€/m2L) = =7.287.932€ INTERIOR **(III) Built-in** = (8UdA x 9.100 UdA) + (8.214m2S x 328€/m2S) + (8.661m2H x 119m2H) = =2.976.251 € BUILT-IN € Pt = Pg+Pp+Pe = 6% + 4% + 6% =16% sobre (I) + (II) + (III). **Cc.4** = [(I) + (II) + (III) x Fg x 1,16 (€Pt)] = (2.109.302€ + 7.287.932+2.976.251€) x 1,000 x 1,16 = **14.353.243 €**	**+5,46%**
	Stage 5: Valuation basic development (Vpb); Vm= Sr (ue) + Cc(ui) + Gp + Bp; Cc(ui) = Vm – Sr(ue) – Gp – Bp Cc.5 = Cc(ui) x m2h.V = [Vm – Sr(ue) – Gp – Bp] x [m2h.V]= Cc.5 = [2.550€/m2c – (35% sobre/2.550) – (37% sobre/2.550)] x 19.974m2h.V]= **Cc.5** = [2.550€/m2c – 893€/m2c – 943 €/m2c] x [19.974m2h.V] = **14.261.436 €**	**+4,79%**

Source: the authors

VI. CONCLUSION

The construction cost estimation systems used in Spain are very underdeveloped, thanks to their general disuse by technicians and professionals from the construction sector. At the same time, the Spanish regulatory framework establishes the need to specify a cost for the project during the design stage (Technical Building Code).

Therefore, the value of this research lies in the importance of specifying cost-approximation models that can be used as useful tools for construction work and the development of building projects.

The model is conceptually based on the three pillars of architecture as described by Vitruvius in his "Ten Books on Architecture": beauty (exterior envelope) + utility (interior functional space) + solidity (footprint on the land).

Our conclusion with regard to the practical application of the Pcr.5n model is that it has fulfilled both its original objectives and formulated hypotheses, achieving a level of precision in estimating costs that is better than 90%. Specifically, the resulting deviations are less than 10%, and range from 4.8% to 9.5% in the analyzed control group.

Additionally, the practical application of this model is fast and simple throughout its five levels of implementation.

This model incorporates the innovative features of volumetric calculation and the box method, neither of which is habitually used in Spain, but whose application is common throughout as another countries like Germany, United States and Australia.The incorporation of these tools is of particular interest given that they result in a significant reduction in margins of error.

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