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Estimating of capital cost of underground car parking projects

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Summary

• Underground parking projects are expensive. The capital cost of underground parking projects has been, and still is, one of the promoter's main economic concerns. Therefore, the capital cost estimation is an essential task in the early stages of underground parking projects. In this context, the promoters mainly use cost estimation models, most of them produced by methodologies with lack of precision and with low performances.
• Over the last years Portugal has embarked on a large programme of underground parking projects in the major cities. The present research work is based on data and knowledge colleted from that programme.
• This paper presents an analysis of the underground parking projects built and underway in Portugal. It discusses the main variables influencing the capital cost of underground parking projects. Finally, it presents a mathematical model for estimating capital cost of this type of project during the planning phase.

Keywords: capital cost, modelling, underground carparks, multiple regression.

Introduction

Road transportation has suffered profound changes over the last decades. Due to the evolution in car technology, credit facilities and financial income, many people in developed countries are car owners nowadays. This has led to an increase in traffic and demand for parking spaces in urban areas. Urban refurbishment has limited irregular parking and decreased parking availability along the streets giving rise to car-parks. Therefore car–parks became essential urban equipments.

Portuguese municipalities have long promoted car-park development in public space, usually through partnership contracts with private companies. Car parks have become an increasing type of real estate projects in Portugal. Due to the lack of available public space on the surface, underground car parks became a current solution. However, this is an expensive type of project and the capital costs involved are one of the promoter's main economic concerns (Lawther, 2000). Therefore, the capital cost estimation is an essential task in the early stages of underground parking projects. In this context, the promoters mainly use cost estimation models, most of them produced by methodologies with lack of precision and with low performances (Fellows and Liu, 1997). The tender process for this type of contract is a difficult undertaking both for the promoter and for the contractor due to difficulty in estimating project costs and benefits. Accordingly, the development of specific technical and economical tools to deal with this problem is important for both parties involved in the process (Curwin and Slater, 2002). This paper presents a model for construction cost estimating of underground car parks applicable to the initial stages of project design.

Underground carparks

Within the context of this research work a survey was carried out on the major underground car park projects within the city of Lisbon. The aim of this survey was to identify the principal features of underground car parks.

Car park projects are vital urban equipments, particularly for major cities. These projects can be classified into four categories: underground parking, surface parking, high rise parking and automatic parking (Município de Lisboa, 1993 and "Regulamento de Segurança contra Incêndio em Parques de Estacionamento Cobertos, 1995). The underground car park projects are generally built in major historic cities where the road traffic is very high. They usually comprise complex and costly building works which are carried out under difficult conditions (NPA, 2000).

The excavation and the foundation walls are risky construction works in any underground car park project. The site's geological and geotechnical conditions should be carefully investigated before the commencement of the construction works. In addition, based on the literature reviewed underground car parks require complex ventilation, drainage, and fire safety systems (Brandon and Ferry, 1999; Spon's, 2000; NPA, 2000). Because these projects are located in large cities, the execution of the construction works may require the deviation of major underground urban services, the interruption of road traffic, and the recovering of major archaeological vestiges.

Usually, the critical need for urban parking is located in the old areas of the major cities. In such areas the supply of parking places can only be achieved through underground parking. In such areas, the excavation work must be carried out with additional care in order to assure the safety of old building and archaeological heritage. Underground parking projects usually require provisional traffic deviations during the construction phase. The road access is a critical element for the performance of the underground parking. The entrances, exits, and internal circulation must conform to strict safety requirements (Município de Lisboa, 1993). Therefore, underground car park projects must be integrated into the city road network and the surrounding urban environment.

An underground parking project is a risky business. It is essential to know at the early stages of the project the capital cost involved in order to manage its risks. The estimation of the capital cost has to deal with all aspects influencing it.

Research method

In order to accomplish the research objectives, relevant literature on the topic was initially reviewed. Thereafter, a set of 20 semi-structured interviews with promoters, planners, contractors and supervisors of this type of project was conducted. The interviewees were selected on the basis of: years of experience; position in the company; type of business; and type of activity within the development process. Finally, a set of case studies was analysed. The initial literature survey helped to produce a questionnaire for the interviews and to establish the cost structures that should be adopted. The purpose of the interviews was to identify the main technical characteristics, construction technologies and marketing procedures usually followed for underground car parks.

Nineteen case study projects corresponding to existing projects within the scope of this research were collected at promoting entities. These case study projects were selected from projects in the City of Lisbon that have being in operation for at least five years. This corresponds to 63% of all the existing projects, including those at early phases of the development process. Data was organised in cost and characteristics record sheets specially created for this survey. For each case one record sheet was produced, containing the following information: case study location, construction technology adopted, present status, areas, capacity, nº of levels, ratio m2/space, type of surface arrangements, participants and cost summary. The cost record sheet of each project further details costs following the cost structure previously established. Similarly, data from other projects were collected following the same procedure. This was later used for experimentation, validation and further refinement of the model.

Cost variables of underground parking projects

The statistic methodology chosen for developing the cost model is presented below – multiple regression, based on the study of the relation between one dependent variable and different independent variables, used to estimate the dependent variable value (Anderson, et al, 1998).

The identification, selection procedures and characterization of the dependent and independent variables that were used for developing the cost model are shown below.

DEPENDENT VARIABLE

The dependent variable is the element which the model will allow to estimate/explain. In a cost estimation model context, that element is the cost indicator. The interviews with car park promoters and others involved in the development of this type of real state projects, was crucial for identifying this variable, because they will be the main users of the cost model.

The analysis of the interviews indicated that the most used cost ratio for estimating capital costs of underground car parks is the cost per gross square metres ratio, instead of the cost per car spaces ratio (Table 1).

Table 1: Relative Importance Index (RII) of cost ratios for underground car park project

Ratio	RII	Order
Cost/m^2	0.84	1
Cost/space	0.67	2

Table 2: List of the Independent variables

	Independent Variables Chosen – Included in the model
x1	Number of underground levels
x2	Surface Arrangements Costs
x3	Square metres/car space (gross area)
x4	Infra-structures deviation Costs
x5	Plant area (square metres)
x6	Foundation walls
	Independent Variables not chosen – Not Included in the model
	Capacity
	Construction Area

These results led to the selection of the dependent variable, which was used in the model – the cost per square metre ratio.

INDEPENDENT VARIABLES

The selection of the independent variables was done by iteration, by simulation of the possible variables combination, permitted by the regression analysis conditions (Person's correlation coefficient), with successive improvements in all stages of the project development. Table 2 presents the initial list, identifying the selected independent variables.

The first variable (x1) quantifies the number of underground levels that comprise the car parks. The cost associated to the surface arrangements (x2) is also an influencing variable in the total cost of the underground car parks. These arrangements include underground substructures: excavations, dewatering, foundations, stairs and substructure walls. Such structures play a significant role in the formation of the capital cost of underground car parks. The square metres/car space ratio (x3) is a ratio that expresses how the available construction area is used for parking. The smaller the ratio, the more profitable for the construction area.

Due to the characteristics of being an underground structure, associated to this type of construction, is the existence of interferences with subsoil infra-structures under the surface of the implantation area, implying the deviation of those. The interviews results indicate a considerable amount for the infra-structures deviation (x4). The plant area (x5) plays a significant role in establishing the layout of the building levels, with a greater or worst space profit for car spaces, that is the reason why this is also a chosen variable.

The geological characteristics, define the construction method of the foundation walls (x6), which has great implications for the capital cost. The capital cost varies according to the type of construction method used for foundation walls.

The principal role of the cost model is to estimate a capital cost value associated to the planned project, which is in agreement with the parameters used in the cost model (Elhag and Boussabaine, 1998). This model can be used in the early stages of the project and should be adapted to the needs of the future users, including promoters, designers and builders. In this context, for an easer estimation function application the variables x2 and x4, associated to specific costs, were converted into pre-defined intervals, called cost levels. The range used between each level is 25.000€. For example, the level 1 includes cost values between 0 and €25,000. The level 2 includes values between €25,001 and €50,000.

The variable x6 reports to the unique qualitative element used in our cost model. To simplify the development and application of the cost model, it was decided to apply to this variable a specific code number to each construction method listed in Table 3. The independent variables, capacity and construction area, were not include in the model on the basis of the results obtained from the significance tests of the different hypothesis of the cost model.

Case Studies

The research was based on nineteen cases, corresponding to nineteen underground car park buildings, which were colleted from promotion and management enterprises. Table 4 shows a list of these cases and some of their generic characteristics, such as the capital construction cost, cost per square metre, gross construction area, plant area, number of parking levels and square metres per space ratio.

The majority of these cases (63.2%) are underground car parks in exploration phase, already working almost five years. The others represent buildings in construction phase, with known capital. From the cases it was found that the average capital cost per square metre of the sample is €355.35/m2, with a standard deviation of €81.82/m2.

Cost model development

The SPSS 11.0 was the software used for the statistical data analysis and for developing the cost model. The selected variables and respective analysis enabled the

Table 3: Variable x6 classification

Code Number	Construction Method
1	Berlin wall
2	Curtain piles
3	Curtain Grouting
4	Cast-in-place shaft walls
5	Berlin wall + Curtain piles
6	Other

Table 4: Characteristics of case study projects

Cases	Total Cost (€)	Total Cost/m2 (€)	Capacity	Gross Area(m2)	Plant Area (m2)	Number of Levels	Ratio m2/space	Construction Method
1	2,381,491	390.79	224	6094	2067	3	27.21	1
2	1,383,376	434.20	111	3186	1320	3	28.70	1
3	2,236,031	300.74	226	7435	3815	2	32.90	1
4	9,581,668	299.94	1150	31945	8405	5	27.78	1
5	2,964,855	381.68	284	7768	3090	3	27.35	2
6	3,197,295	302.20	463	10580	3680	3	22.85	1
7	2,301,758	325.34	284	7075	2402	3	24.91	1
8	1,833,092	293.06	208	6255	2273	2	30.07	1
9	2,119,896	221.86	398	9555	4835	1	24.01	2
10	4,294,575	463.28	367	9270	3150	3	25.26	1
11	1,251,788	264.09	169	4740	1605	3	28.05	2
12	1,326,483	418.45	105	3170	1585	2	30.19	1
13	2,406,989	457.60	173	5260	2720	2	30.40	2
14	4,912,122	490.08	316	10023	3370	4	31.72	5
15	2,055,047	366.32	182	5610	2820	2	30.82	6
16	3,122.475	259.30	404	12042	4475	3	29.81	1
17	3,107.511	447.12	195	6950	1900	4	35.64	1
18	3,786.948	255.70	447	14810	3245	5	33.13	3
19	3,743.523	380.05	360	9850	3300	3	27.36	2

definition of a multiple regression equation based on the chosen independent variables. Based on this equation the relevant statistic elements defining the explanation level for the dependent variable were analysed, namely:

a)the correlation coefficient (R);

b) the determination coefficient (R2);

c) adjusted determination coefficient (R2a);

d) the estimated standard error, F value and respective significance level, which are the basis for the regression analysis.

Table 5 presents the values of these elements. They were checked for the selected cost model which facilitated the global model significance test. During the refinement process of the cost model the outliers were eliminated.

As can be seen, the last regression equation (A5) has a correlation coefficient of 100%, which confers a high level of explanation to the dependent variable. It also showed on Table 5 that the regression equation (A3), confers also a high level of explanation, with a correlation coefficient of 97.30%, including 80% of the initial cases studies.

The global model significance and the multiple regression basis hypotheses were tested and verified. In order to validate the methodology, the parameters significance was also tested (t-test), which enabled the testing of individual importance in explaining the dependent variable of each parameter. Table 6 summarises the parameters values and the respective standardized values (beta coefficients), standard error and t (Student) function values with the identified significance levels.

The observed t function values allowed us to reject zero hypothesis, concluding that all the selected independent variables included in the model, were important to explain the dependent variable. Therefore, this hypothesis was chosen to represent the cost model, expressed in the following equation:

$$Yi = 300.248 - 25.374x_1 + 11.080x_2 + 6.089x_3 + 6.938x_4 - 3.739E\text{-}02x_5 - 15.014x_6$$

COST MODEL VALIDATION AND REFINEMENT

The validation of the cost model was in its refinement. Thus, six new cases were selected with the same generic characteristics of the investigation cases for validating and refining the proposed cost model. Table 7 summarizes some of characteristics of the cases used during validation.

Most of these cases have a similar size to the 19 case study projects, except case EC 3 with a unique dimension which is smaller than the rest of the cases either in terms of the gross area and the parking spaces. This case has 1,243 square metres of gross area and 69 car spaces. This case was chosen to test the model performance for small underground car parks.

Regarding the ratio cost (cost per square metre), it can be seen that the values are between the limits of the interval verified for the investigation cases, except for case EC 6 that exceeds the maximum value of case study projects by €82.75/m2.

Table 5: Statistic regression equation analysis - Global model significance test

Hypotheses of the Model		N	R	R2	R2a	Estimated Standard Error	F ANOVA	Sig.
A	A1	19	0.649	0.421	0.132	76.21002	1.456	A
	A2	15	0.882	0.779	0.613	44.21048	4.690	
	A3	12	0.973	0.947	0.883	22.91438	14.856	
	A4	10	0.996	0.992	0.976	10.97049	62.036	
	A5	9	1.000	0.999	0.998	3.49141	553.551	

Table 6: Regression equation parametres - t - student test

	Parameters		Standardized Parameters	t	Significance
	B	Standard Error	Beta		
(Constant)	300.248	29.586		10.148	0.010
X1	-25.374	3.384	-0.238	-7.498	0.017
X2	11.080	0.542	0.728	20.440	0.002
X3	6.089	0.880	0.182	6.921	0.020
X4	6.938	0.503	0.608	13.784	0.005
X5	-3.739E-02	0.001	-1.129	-47.851	0.000
X6	-15.014	1.012	-0.415	-14.834	0.005

Table 7: Experimentation cases characteristics

Cases	Total Cost (€)	Total Cost/m2 (€)	Capacity	Gross Area (m2)	Plant Area (m2)	Ratio m2/space	Number of Levels	Construction method
EC 1	5, 168,688	321.82	603	16,061	5,354	26.63	3	1
EC 2	3,214,478	454.21	207	7,077	2,622	34.19	2	5
EC 3	610,668	316.84	69	1,927	1,196	27.93	2	1
EC 4	2,247,000	416.40	197	5,396	2,800	27.39	2	1
EC 5	2,738,400	411.81	220	6,650	2,400	30.23	3	1
EC 6	6,505,307	572.82	393	11,357	3,000	28.90	4	1

Table 8: Absolute deviation values verified in the costs per square metres and total costs versus model determined values for the experimentation cases

Case	Deviation y-y' (€)	Total cost deviation (€)	Total cost deviation (%)
EC 1	3.92	62,901	1.22
EC 2	43.42	307,303	9.56
EC 3	90.12	173,685	28.44
EC 4	10.40	56,102	2.50
EC 5	10.03	66,700	2.44
EC 6	28.10	319,146	4.91

Finally, in respect of the global cost, only the case EC3 presents a lower value, €640.851, which is the difference between the lowest cost in Table 4 and the EC3 in Table 7. The deviation values obtained from validation of the cost model are presented in Table 8.

The analysis of these deviation values allowed us to test the performance of the cost model in predicting the capital cost of underground car parks. The values in Table 8 show that four of the six cases present a perfectly acceptable capital cost deviation value, less than 5%.

One of the other two cases presents an acceptable deviation, less than 10 %, and the other an unacceptable 28%. However, there seem to be sufficient reasons to explain these deviation values, which are presented below.

The case EC2 corresponds to an underground car park built with a different construction method for foundation walls from the rest of the cases. It also has a very high square metre per car space ratio compared to the investigation and experimentation samples average. The EC3 case represents a parking project with dimensions uniquely lower than the minimum values verified in the investigation cases, which can justify the low performance of the cost model in estimating the capital cost for underground car parks with such dimensions.

The deviation of the capital cost value ranges from €56.10 to €319.15 with the average of €164.30 and the standard deviation of €12331.

The analysis of the deviation values allowed us to conclude, that in a general form, the cost model performance is acceptable for estimating the capital cost of underground car parks in the early stage of their implementation.

Conclusions

Underground car parking solutions are used to satisfy the parking needs of major cities. Their implementation involves a number of risks. In addition the underground parking projects are expensive. Thus, the estimation of the capital cost of the underground parking projects during the planning stages is a critical task.

This paper presents a mathematic model for estimating the capital costs of underground parking projects. This cost model was developed taking into account data from 20 interviews, 19 research cases and 6 experimental cases associated with implemented projects.

The cost model and the research findings provide new cost planning tools in the field of underground parking projects. This provides a list of variables to build a database for elemental cost information and a methodology for cost analysis of underground car park development. The cost model provides a mathematical tool for preliminary estimating and comparing the cost of alternative designs. It is a result of a process which combined development and testing of different hypothesis. The validation and refinement process undertaken allowed the findings from the study to be confirmed. In addition, the research work allowed us to apply the existing theory to practice.

The cost model was validated using real project cases for evaluating its field efficiency and effectiveness.

The results obtained and the tests carried out during the validation showed that the proposed model can be used for estimating the capital cost at early stages of the project using few data and within some reasonable precision. The cost model is an important tool for the cost planners and designers during the design phase.

The major explanatory variables of the capital cost of underground parking projects have been outlined in this paper. These are the dependent variables which have a major influence on the capital cost. However, the cost model presented has some limitations. The scope of the research is a major limitation in the sense that it only covers the underground car park projects in the City of Lisbon. The model can be improved however with further refinement using new case study projects either from historical and residential areas of Lisbon or projects from other countries to present an international dimension to the study. The methodology presented in the paper allows this to be done.

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