Six International Conference on Construction in the 21st Century (CITC-VI)
"Construction Challenges in the New Decade"
July 5-7, 2011, Kuala Lumpur, Malaysia

A Cost Estimation Model in Pre-Design Phase

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Abstract

A cost estimation model that is developed for residential buildings to be used in pre-design phase and based on the factors that affect building cost in pre-design phase is introduced in this study. Factors affect cost in pre-design phase and affecting ratios of these factors are determined. As using affecting ratios of factors on cost, the conversion coefficients are determined and they are used for developing the cost estimation model. This is a conversion model. This model is explained with a formula and its usage is facilitated with using computer programs. It can be used in the future with using building cost index. After cost estimation models in the pre-design phase are introduced, the developed model is compared with other cost estimation models in the pre-design phase. The values of per m^2 cost that are calculated with new model are compared to Ministry of Public Works Method values. As Ministry of Public Works Method is used after design phase, its values are close to the actual cost. The values of per m^2 cost that are calculated with new model are -4.6% and 5.4% different from the values of per m^2 cost that are calculated with Ministry of Public Works Method.

Keywords

Cost estimation, cost estimation model, factors affect cost, conversion model.

1. INTRODUCTION

When the entire construction process is considered, the preliminary design phase is where cutting down the costs is the easiest. After the design is done, the building cost should be calculated and, should the result be over the target cost, changes must be made in the design in order to lower the cost. However, there is also the cost of the time spent on the design process, and the process itself. Yet, if one knows, before starting the design, which factors affect the costs and to what extent, then the design can be aligned accordingly, and the costs can thus be taken under control in the preliminary design phase, ensuring that the target cost is reached. In this way, the cost of revisits in the design phase is also compensated for. This is ensured by using the models in the preliminary design phase.

In Turkey, although the residential sector is quite predominant, research on cutting down residential costs are limited. When building a low-cost house, the decisions taken during the preliminary design phase are particularly important. The main decisions concerning how economic a building will be are taken during this phase; therefore, it is the phase where the chance of lowering the costs is the highest. Around the world, many researchers and organizations have conducted studies to lower the costs in the preliminary design phase, produced cost data that can be used in this phase, and created cost databanks. It is not possible to use in Turkey the advanced cost estimation models and cost data produced and developed in other countries, because the use of these data is limited to the geography and economic areas where they were originally created.

The purpose of this study is to introduce the cost estimation model developed based on factors affecting the cost and which can be used for residential buildings in the pre-design phase. To this end, studies from Turkey and abroad indicating the factors affecting costs in the pre-design phase and the extent to which these factors affect the costs in figures will be evaluated. These factors will ensure that the factors that will be the basis of the model to be developed are identified, and that the data obtained are tested. With the data obtained, the model will be established and the usability of the model will be tested with examples.

2. Factors Affecting Cost In Pre-Design Phase

In the study, previous studies showing the effect of factors affecting the cost in the pre-design phase on the building cost will be used both in determining the base project, which is desired to give the minimum cost, and also in assessing the data obtained from the studies. These factors have been identified as quality, number of storeys, plan shape, flat size, storey height, number of flats per storey, basement condition and circulation area. The results of researches accessed through the literature are given in Table 1.

Table 1. Results of researches about factor-cost relationship

factor groups	categories in factor groups	Hannover Construction Research Institute (Kraentzer,1962)		Durmus, A. (Durmus, 1994)		Deters, K. (Deters, 1982)		Tubitak Construction Research Institute (Pisirci *et al.*, 1986)		Republic of Turkey Prime Ministry Housing Development Administration of Turkey (Ciracı, 1996)		Bathurst, P.E., Butler, D.A. (Buthurst and Butler, 1982)		Seeley, I.H. (Seeley, 1986)	
		TL/m²	TL/unit	TL/m²	TL/unit	TL/m²	TL/unit	TL/m²	TL/unit	TL/m²	TL/unit	TL/m²	TL/unit	TL/m²	TL/unit
quality category	**3rd category**	100		100											
	2nd category	107		124											
	1st category	124		131											
	Luxury category	133		202											
number of stories	3		109				89	-	-						
	4		101				81-86	100	100						
	5		100				97-103	-	-	106 (1-	5 storied)				
	6		109				95-100	117	121	100 (6-	12 storied)				
	7		104				93-98	-	-	103 (12-	17 storied)				
	8		-				92-97	98	101						
	9		-					-	-						
	10		-					95	98						
plan shape	**square**		-							100	square	100		100	(square)
	rectangular									102	L shaped	107-112		101	12.2x7.6
	star shaped									105	star shaped			106	15.2x6.0
	H shaped									108	U shaped			116	20.0x4.6
										113	T shaped			109	(T shaped)
flat size	< 75 m²	100(60 m²)	100											101	75.3 m²
	75 m²-125 m²	108(70 m²)	92-93											100	85.1 m²
	125 m²-175 m²													94	106.5 m²
	> 175 m²														
storey height	**2.70 m.**											100	(h:3.0 m.)		
	2.80 m.											134	(h:4.0 m.)		
	2.90 m.														
	3.00 m.														
number of flats per storey	1		117				116								
	2		105				105								
	3		101				100								
	4		100												
basement condition	**without basement**		100												
	with basement		116-140												
lift condition	**without a lift**														
	with lift														
transparency rate (window area/ external wall area)	**0.20**														
	0.25														
	0.30														
	0.35														

3. Conversion Models

In conversion models, a specific sample project is selected, and the cost of the new project is calculated using the costs analyses of the sample project. When calculating the cost of the new project, conversions are made pro rata the changes that will be brought forward by the factors affecting cost, on the cost data of the sample project.

Belfield and Everest studied a model developed in consideration of quality, size, layout and time factors, which were recognized as the factors having the most effect on costs (Belfield *et al*., 1977). This model was transformed into a computer software in 1985 by Brandon, Moore and Main, which made it easier to use. (Brandon *et al*., 1985) In the study, it was accepted that there is a linear relationship between space and cost per m^2. However, it could not be proven with samples. Seeley took as a basis a cost analysis of a building similar to the building for which the calculations were to be done, based on building components (Seeley, 1986). The differing characteristics of the new building compared to the building at hand were determined; the increases and decreases on the building component costs caused by these characteristics were calculated; then the new buildings component costs and the component costs were added up to find the cost. It was accepted that any decrease in storey height would also cause a pro rata decrease in the cost, yet the basis of this acceptance, i.e. the reasons why this was accepted, was not explained. It cannot be said that a reduction in quantity would result in an equal rate of reduction in costs. In their study on preliminary cost estimation, Ferry and Brandon chose a sample project with costs for m^2 known and resembling the project for which the costs were to be calculated (Ferry *et al*., 1986). The study sought the result by calculating the costs, the consequences of the differences between the actual project and the sample project. It was a conversion problem. The conversion took into consideration the market conditions, the shape differences (size, number of storeys), the differences in building quality, the plumbing differences, the scope differences and the land and ground differences, as well as various other factors. However, this conversion operation is highly complicated with a difficult calculation system. Calculating the cost difference for each and every factor is a challenging and time-consuming process.

In study by Ferry and Brandon on “A Component Model Based on Floor Area”, building components are adjusted according to quality, quantity and time, after which component costs are added to obtain the total cost (Raftery, 1991). In this model, the database of Building Cost Information Service (BCIS) was used. However, the available source does not contain sufficient information on adjusting quality and quantity or on the use of the model. Means, in his studies dated 1988, 1992, 1993,1994 and 1996, used a methodology based on factors affecting the cost (Killingsworth, 1988), (Means, 1993), (Means, 1994), (Cox *et al*., 1996), (Bledsoe, 1992), which was also a method developed on the assumption that as area increases, the m^2-cost decreases, similar to the study appearing in- 1977’ in Architects’ Journal and the study dated 1985 by Brandon, Moore and Main. However, it was a more advanced model, as it was based on the data in the Means Information Bank that consisted of data from existing buildings, and since the building types were categorized and the relationship between cost and size was not linear. However, this model also considers only the size, time and layout factors. Yet, there are other factors that have more effect on cost. For example, quality differentiation is a factor that should not be underestimated in terms of its effect on cost.

4. A Cost Estimating Model in Pre-Design Phase

The model developed in this study is a conversion model. A project with identified characteristics is accepted as the base project, and per m^2 cost of this base project is used in calculating per m^2 costs of the conversion model and other projects, and their total cost. The per m^2 cost of the new project changes as the characteristics of the new project differentiate from the characteristics of the base project.

4.1. Method

Cost-effecting factors, those identified for use in model development were used to create groups called factor groups. As a result of the literature scan, the factors to be used in this model were identified as quality, number of storeys, plan shape, flat size, storey height, number of flats per storey, and the basement condition. In addition to these factors, the model also includes the lift condition and the transparency rate factors. These factors constitute the factor groups.

For developing the model, first of all it is necessary to identify the characteristics of the base project. The base project, which is taken as a basis for the cost estimation model, which is included in all factor groups and which is accepted to meet the minimum cost per m^2 requirement, was identified as a reinforced concrete residential project in third category construction quality with an average flat size of 100 m^2, where four flats connected to one staircase, with a square-shape plan, five storeys with a storey height of 2.70 m, window area/external wall area ratio of 0.20, without lift and basement, based on the research found in the literature and the conditions of Turkey. Base project was designed according to the identified factor characteristics. The construction procedures for the base project were determined, and the total cost of the base project was calculated using the 2005 unit prices (www.birimfiyat.net) and measurement standards of the Ministry of Public Works. The total cost of the base project was divided into the total building area to identify per m^2 cost of the base project. The calculated costs include only the costs related to construction works.

For creating the factor groups, all the characteristics of the base project were kept constant, and only the characteristic related to that factor was changed. The projects for these classes were designed, and per m^2 costs for these 28 different projects were calculated using the same method. The characteristics of the 28 different projects making up the factor group classes are given in Table 2.

Table 2. Properties of projects

project name	quality categories	number of storeys	plan shape	flat size	storey height	number of flats per storey	lift condition	basement condition	window area/ external wall area
PR-01	3rd category	5	square	75-125 m^2	2.70 m.	4	without a lift	without basement	0.20
PR-02	2nd category	5	square	75-125 m^2	2.70 m.	4	without a lift	without basement	0.20
PR-03	1st category	5	square	75-125 m^2	2.70 m.	4	without a lift	without basement	0.20
PR-04	luxury category	5	square	75-125 m^2	2.70 m.	4	without a lift	without basement	0.20
PR-05	3rd category	3	square	75-125 m^2	2.70 m.	4	without a lift	without basement	0.20
PR-06	3rd category	4	square	75-125 m^2	2.70 m.	4	without a lift	without basement	0.20
PR-07	3rd category	6	square	75-125 m^2	2.70 m.	4	with lift	without basement	0.20
PR-08	3rd category	7	square	75-125 m^2	2.70 m.	4	with lift	without basement	0.20
PR-09	3rd category	8	square	75-125 m^2	2.70 m.	4	with lift	without basement	0.20
PR-10	3rd category	9	square	75-125 m^2	2.70 m.	4	with lift	without basement	0.20
PR-11	3rd category	10	square	75-125 m^2	2.70 m.	4	with lift	without basement	0.20
PR-12	3rd category	5	rectangular	75-125 m^2	2.70 m.	4	without a lift	without basement	0.20
PR-13	3rd category	5	star shaped	75-125 m^2	2.70 m.	4	without a lift	without basement	0.20
PR-14	3rd category	5	H shaped	75-125 m^2	2.70 m.	4	without a lift	without basement	0.20
PR-15	3rd category	5	square	<75 m^2	2.70 m.	4	without a lift	without basement	0.20
PR-16	3rd category	5	square	125-175 m^2	2.70 m.	4	without a lift	without basement	0.20
PR-17	3rd category	5	square	>175 m^2	2.70 m.	4	without a lift	without basement	0.20
PR-18	3rd category	5	square	75-125 m^2	2.80 m.	4	without a lift	without basement	0.20
PR-19	3rd category	5	square	75-125 m^2	2.90 m.	4	without a lift	without basement	0.20
PR-20	3rd category	5	square	75-125 m^2	3.00 m.	4	without a lift	without basement	0.20
PR-21	3rd category	5	square	75-125 m^2	2.70 m.	1	without a lift	without basement	0.20
PR-22	3rd category	5	square	75-125 m^2	2.70 m.	2	without a lift	without basement	0.20
PR-23	3rd category	5	square	75-125 m^2	2.70 m.	3	without a lift	without basement	0.20
PR-24	3rd category	5	square	75-125 m^2	2.70 m.	4	with lift	without basement	0.20
PR-25	3rd category	5	square	75-125 m^2	2.70 m.	4	without a lift	with one basement	0.20
PR-26	3rd category	5	square	75-125 m^2	2.70 m.	4	without a lift	without basement	0.25
PR-27	3rd category	5	square	75-125 m^2	2.70 m.	4	without a lift	without basement	0.30
PR-28	3rd category	5	square	75-125 m^2	2.70 m.	4	without a lift	without basement	0.35

Per m^2 costs for the projects were compared within the factor groups. Per m^2 costs of the projects were used in identifying the conversion coefficients, which are the basis of the model. To identify the conversion coefficient for the factor group class, per m^2 costs of the projects included in the factor group were divided into cost per m^2 of the base project. Per m^2 costs for 28 different projects and conversion coefficients are given in Table 3 (Bostancioglu, 2006).

When the data obtained in Table 3 were compared with the literature data in Table 1, it was seen that the results showed parallelism.

Table 3. Conversion coefficients of categories in factor groups

A	B	C	D	E
factor group	**factor group class**	**cost per m^2 (TL/m^2) (2005)**	**relative cost per m2**	**conversion coefficient**
quality category	**3rd category**	**180.07**	**100**	**1.000**
	2nd category	202.35	112	1.124
	1st category	228.34	127	1.268
	luxury category	256.53	142	1.425
number of storeys	3	193.03	107	1.072
	4	184.44	102	1.024
	5	**180.07**	**100**	**1.000**
	6	180.42	100	1.002
	7	178.42	99	0.991
	8	177.08	98	0.983
	9	177.36	98	0.985
	10	176.91	98	0.982
plan shape (external wall area/floor area	**square (0.562)**	**180.07**	**100**	**1.000**
	rectangular (0.562)	182.21	101	1.012
	star shaped (0.634)	189.74	105	1.054
	H shaped (0.724)	192.06	107	1.067
flat size	<75 m^2	190.3	106	1.057
	between 75-125 m^2	**180.07**	**100**	**1.000**
	between 125-175 m^2	171.76	95	0.954
	>175 m^2	168.51	94	0.936
storey height	**2.70 m**	**180.07**	**100**	**1.000**
	2.80 m	183.44	102	1.019
	2.90 m	186.55	104	1.036
	3.00 m	189.53	105	1.053
number of flats per storey	1	211.08	117	1.172
	2	194.63	108	1.081
	3	191.09	106	1.061
	4	**180.07**	**100**	**1.000**
basement condition	**without basement**	**180.07**	**100**	**1.000**
	with one basement	190.52	106	1.058
lift condition	**without a lift**	**180.07**	**100**	**1.000**
	with lift	182.09	101	1.011
transparency rate window area/ external wall area	**0.20**	**180.07**	**100**	**1.000**
	0.25	181.15	101	1.006
	0.30	182.24	101	1.012
	0.35	183.32	102	1.018

4.2. Usage of the Model

To calculate the cost of the new project, the characteristics of the new project differing from the base project are determined, and then the conversion coefficients are selected according to these differing characteristics. The sum of conversion coefficients for the new project are then subtracted from the sum of conversion coefficients for the base project to identify how higher or lower cost per m^2 of the new project is from cost per m^2 of the base project, in percentage. The obtained value is then multiplied with the cost per m^2 of the base project to obtain the differentiating cost of the new project from the base project; then, this value is added to the cost per m^2 of the base project to obtain cost per m^2 of the new project. Cost per m^2 calculated for the new project is for the year of 2005 and can be updated using the cost index.

The model can be used with the help of formulas. Conversion coefficients are taken from Column E in Table 3. For updating the prices, Prime Ministry Republic of Turkey, Turkish Statistical Institute, Building Construction Cost Index is used (www.tuik.gov.tr).

The model can also be expressed in formula in line with the findings obtained:

$$\mathbf{TL/M2\ YB = [TL/M2\ BB + TL/M2\ BB x(\Sigma DK_{K1} - \Sigma DK_{K0})]\ x \dot{I}_Z} \quad (1.1)$$

$$\mathbf{\Sigma DK_1 = DK_{K1} + DK_{KDA1} + DK_{PB1} + DK_{DB1} + DK_{TS1} + DK_{KA1} + DK_{KY1} + DK_{SO1} + DK_{BO1}} \quad (1.2)$$

$$\mathbf{\Sigma DK_0 = DK_{K0} + DK_{KDA0} + DK_{PB0} + DK_{DB0} + DK_{TS0} + DK_{KA0} + DK_{KY0} + DK_{SO0} + DK_{BO0}} \quad (1.3)$$

TL/M2 YB = cost per m^2 of new building
TL/M2 BB = cost per m^2 of base building
ΣDK_1 = sum of new building's conversion coefficients
ΣDK_0 = sum of base building's conversion coefficients
DK_{K1} = new building's conversion coefficient of quality category
DK_{KO} = base building's conversion coefficient of quality category
DK_{KDA1} = new building's conversion coefficient of number of flats per storey
DK_{KDA0} = base building's conversion coefficient of number of flats per storey
DK_{PB1} = new building's conversion coefficient of plan shape
DK_{PBO} = base building's conversion coefficient of plan shape
DK_{DB1} = new building's conversion coefficient of flat size
DK_{DB0} = base building's conversion coefficient of flat size
DK_{TS1} = new building's conversion coefficient of lift condition
DK_{TSO} = base building's conversion coefficient of lift condition
DK_{KA1} = new building's conversion coefficient of number of storeys
DK_{KA0} = base building's conversion coefficient of number of storeys
DK_{KY1} = new building's conversion coefficient of storey height
DK_{KYO} = base building's conversion coefficient of storey height
DK_{SO1} = new building's conversion coefficient of transparency rate
DK_{SO0} = base building's conversion coefficient of transparency rate
DK_{BO1} = new building's conversion coefficient of basement condition
DK_{BO0} = base building's conversion coefficient of basement condition
$\dot{I}_Z$ = construction cost index value

After the factor group classes are written down in the calculation table prepared in Microsoft Excel, as seen in Table 4, the relevant conversion coefficients for them are selected from Column E in Table 3. Turkish Statistical Institute Building Construction Cost Index is used for updating the cost value.

4.3. Testing the Model

By designing 7 different projects not included in the factor group classes, the costs per m^2 of the projects are calculated with the developed model and Ministry of Public Works method for the year 2010 (Akcali,2010). The per m^2 cost values calculated are given in Table 5 and properties of the 7 projects used in testing the model are given in Table 6. As seen in Table 5, per m^2 costs of the 7 projects calculated with the developed model give a deviation of -4.6% to 5.4% when calculated with Ministry of Public Works method. Ministry of Public Works method is a cost estimation and calculation model. It is used in application project and application phase.

Table 4. Cost calculation with developed model (2010)

factor groups	factor group classes	conversion coefficients
quality category	1st category	1.268
number of flats per storey	2	1.081
plan shape (external wall area/floor area	H shaped	1.067
flat size	between 125-175 m^2	0.954
lift condition	with lift*	1.000
number of storeys	6	1.002
storey height	2.80 m	1.019
window area/ external wall area	0.15	1.000
basement condition	with one basement	1.058
sum of the conversion coefficient of the new project		9.449
sum of the conversion coefficient of the base project		9.000
conversion coefficient of the new project		1.449
index value (2010)**		1.4249
cost per m^2 of the base project (TL/m^2)		*180.07*
cost per m^2 of the new project (TL/m^2)		*371.79*

*Since buildings with more than 5 storeys must have a lift pursuant to Type Development Regulation, the lift factor has entered the construction cost, together with number of storeys factor, for buildings with more than 5 storeys. Although buildings with more than 5 storied are in the with lift class, the conversion coefficient used was 1.00.

**Prime Ministry Republic of Turkey, Turkish Statistical Institute, Building Construction Cost Index, 1. quarter 2010 (tuik.gov.tr)

Table 5. Cost per m^2 of the 7 projects calculated with developed model and Ministry of Public Works method and the deviations

project name	Ministry of Public Works method cost per m^2 (2010)	new model cost per m^2 (2010)	deviation (%) (2010)
PR-29	370.48	371.79	0.4
PR-30	317.68	334.84	5.4
PR-31	296.02	303.02	2.4
PR-32	393.34	412.07	4.8
PR-33	365.39	368.71	0.9
PR-34	344.42	328.42	-4.6
PR-35	292.80	291.48	-0.5

Table 6. Projects used in testing the model

project name	quality categories	number of storeys	plan shape	flat size	storey height	number of flats per storey	lift condition	basement condition	window area/ external wall area
PR-29	1st category	6	H shaped	125-175 m^2	2.80 m.	2	with lift	with one basement	0.15
PR-30	2nd category	6	H shaped	125-175 m^2	2.80 m.	2	with lift	with one basement	0.15
PR-31	3rd category	6	H shaped	125-175 m^2	2.80 m.	2	with lift	with one basement	0.15
PR-32	luxury category	6	H shaped	125-175 m^2	2.80 m.	2	with lift	with one basement	0.15
PR-33	luxury category	5	rectangular	75-125 m^2	2.70 m.	4	without a lift	without basement	0.20
PR-34	1st category	5	rectangular	75-125 m^2	2.70 m.	4	without a lift	without basement	0.20
PR-35	2nd category	5	rectangular	75-125 m^2	2.70 m.	4	without a lift	without basement	0.20

5. Conclusion

As a result of the study, the cost-effecting rates of factors effecting cost in the preliminary design phase were identified based on projects designed for the conditions of Turkey, after which the conversion coefficients were determined using these ratios, to develop a cost estimation model that could be used in the preliminary design phase.

A cost estimation model was developed using the conversion coefficients obtained as a result of the study. The conversion coefficients can be used in formulas to calculate the cost per m^2 and total costs of the new project. Using the advantages of computer programmes, the model was made easier to use. Since the developed cost estimation model can be updated with the construction cost index, it can also be used for future works.

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