09 Oct 1970

Feasibility of Prefabrication in Low Cost Housing

Dogan Sorguc

David Arditti

Taha Aksoy

FEASIBILITY OF PREFABRICATION IN LOW COST HOUSING

By

Dr. Dogan Sorguc*
David Arditti**
Taha Aksoy***

INTRODUCTION

Housing construction which is defined as "one of the thermometers that faithfully reflects the economic situation of the country"(1) has strong social, economical and political impacts. Those are the facts explaining why industrially advanced countries are producing remarkably more dwellings that the developing countries. Studies made in sixties showed that at the beginning of this decade the output of USSR has reached 15 dwellings/1000 population(2) while the developing countries could produce 2 or maximum 5. USA could realize 7.4 between 1963-67. They, now, decided to improve it, starting the "Operation Breakthrough" by which a mass production of housing will be launched all over the country, the target being the provision of housing for low income families and therefore low cost housing; the problem which arises is that of the high productivity and rationalization.(3)

The low cost housing or social housing is nowadays completely lacking in developing countries due to their economic conditions as the savings are not enabling public subsidies to carry out large housing projects. The amount of public investments in housing was a. g. only 1.6% of housing investments in Turkey during 1967(4), thus furnishing one of the main social criterias of developing countries. On the other hand the shortage of housing in developing countries excels terrifying sizes due to high rate of increase of population and urbanization. The only way to counteract this trend is rationalization on sector level in order to increase the productivity and to decrease cost of the construction.

For purpose of planning and control, objective and standard model of analysis is required. This model should permit evaluation of any measure or comparison of different systems to be considered. In the following article such a model(2) is presented to find out the fiasibility of prefabrication in housing construction, laying the emphasis on closed system of prefabrication, much envied by developing countries. This method is also used to a certain extent in some of the industrial countries of Europe, like France versus rationalised traditional housing construction in Western Germany. To demonstrate the application of this model an example is calculated by means of Turkish data. Due to the fact that some of those data obtained from different sources as the State Planning Organization, the State Institute of Statistics, the Ministry of Public Works and construction of dwellings were inconsistent and the data for prefabricated construction were insufficient, it has been found necessary to fix some assumptions with reference to the application performed in other countries.

1. THE COST MODEL

According to research works of Dr. Doğan Sorguc performed in 1967, as cost system of housing production has been defined as follows (2) :

$$C = C_1 + C_2 + C_3 + \beta C_4$$

where :

C = Total cost of housing

C_1 = Land cost

C_2 = Interest cost

C_3 = Consultation cost

C_4 = Production cost

β = Factor of benefit

$= 1 + \eta$

η = Factor of contractor's benefit

The production cost (C_4) may, in its turn, be fefined as :

$$C_4 = C_{41} + C_{42} + C_{43} + C_{44} + C_{45} + C_{46}$$

where

C_{41} = Cost of moving in, ie erecting equipment and plants

C_{42} = Site overhead cost, ie cost in site office

C_{43} = Business cost, ie costs in central office (administration costs etc.)

C_{44} = Capacity cost, ie costs of labor and equipment

C_{45} = Construction materials cost

C_{46} = Finishing cost

The capacity cost (C_{44}) is directly proportional with the number of producing workers (and the quantity of machinery), the working time of workers (and of machinery), and is indirectly proportional with the labor (and machinery), job and management efficiencies. It may, therefore, be defined as:

$$C_{44} = C_{44A} + C_{44B}$$

where

C_{44A} = Cost of labor

C_{44B} = Cost of machinery

The construction materials cost (C_{45}) is directly proportional with the quantity of materials used, the unit cost of materials, transportation distance and unit cost of transportation. This factor, may be considered for main materials such as:

$$C_{45} = C_{451} + C_{452} + C_{453} + C_{454}$$

where

C_{451} = Cost of cement

C_{452} = Cost of reinforcing steel

C_{453} = Cost of timber

C_{454} = Cost of bricks and tiles

The finishing cost (C_{46}) is mainly due to labor and materials used for finishing:

$$C_{46} = C_{461} + C_{462}$$

where

C_{461} = Labor cost for finishing

C_{462} = Materials cost for finishing

2. EVALUATING THE FACTORS OF COST

Before starting to calculate the feasiblity of prefabrication in housing production, it has been found necessary to evaluate the weight (or shares) (W) of each of each of the above defined factors in the cost function. Any factor of cost (C_K) may thus be written in relation to another one (C_N) as :

$C_K = w_K^N \cdot C_N$ $\quad$ w_K^N giving the percentage of C_K in C_N

a) It has been evaluated that the large housing production, the Land Cost (C_1) should not be more that 5-10% of the Production Cost (C_4) (2). Taking an average of 7.5%, this gives:

$$w_1^4 = 0.075 \quad \text{or}$$

$$C_1 = 0.075\ C_4 \quad \ldots\ldots\ldots\ldots (1)$$

In the same way, it has been found out that the consultation Cost (C_3) amounts approximately to 3-5% of the Production Cost (C_4) (4). An average of 4% gives:

$$w_3^4 = 0.04$$

$$\text{or } C_3 = 0.04\ C_4 \quad \ldots\ldots\ldots\ldots (2)$$

The American and German literature generally assume an average investment of $\frac{C_3 + C_4}{2}$ over the construction period.

---

*Assistant Professor, Middle East Technical University, Ankara, Turkey.
**Middle East Technical University, Ankara, Turkey.
***Middle East Technical University, Ankara, Turkey.

Together with the interest of Land Cost (C_1) (as shown in the following graph), third relation may be obtained.

$$C_2 = n.i. \frac{(C_1 + C_4)}{2} \quad \ldots\ldots\ldots (3)$$

Assuming an interest rate of i = 6%, a duration of n = 1 year and using the basic cost model:

$$C = C_1 + C_2 + C_3 + C_4 \quad \ldots\ldots\ldots (4)$$

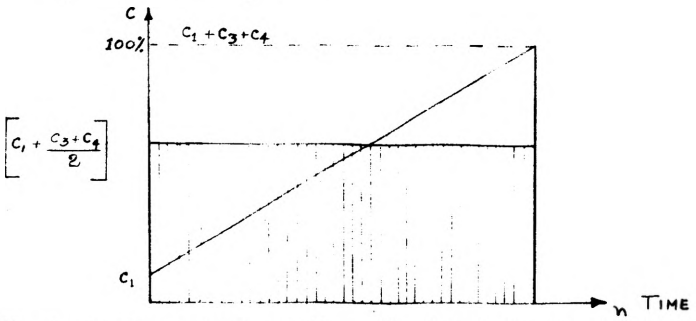
following results may be obtained:

$C_1 = 0.065 \quad C \quad (\text{or } w_1^o = 0.065)$

$C_2 = 0.030 \quad C \quad (\text{or } w_2^o = 0.030)$

$C_3 = 0.033 \quad C \quad (\text{or } w_3^o = 0.035)$

$C_4 = 0.870 \quad C \quad (\text{or } w_4^o = 0.870)$



b) A research made by UN in 1963 provides that the Erecting Cost (C_{41}), The Site Overhead Cost (C_{42}), and the Business Cost (C_{43}) from about 5-10% of the Production Cost (C_4) excluding the Finishing Cost (C_{46}) (5). In Turkey, due to special conditions of the construction industry this percentage has been taken as 10%. Consequently:

$$C_{41} + C_{42} + C_{43} = 0.10\ (C_4 - C_{46}) \quad \ldots\ldots (1)$$

The same statistics show that the Capacity Cost (C_{44}) varies between 30-40% of ($C_4 - C_{46}$) and that the Building Materials Cost (C_{45}) is about 60% of ($C_4 - C_{46}$) in Asian countries.
It may, therefore, be written:

$$C_{44} = 0.30\ (C_4 - C_{46}) \quad \ldots\ldots\ldots (2)$$

$$C_{45} = 0.63\ (C_4 - C_{46}) \quad \ldots\ldots\ldots (3)$$

On the other hand, studies made with competent contractors and authorities in Turkey resulted that the Finishing Cost (C_{46}) is approximately the 40% of the Production Cost (C_4).

$$C_{46} = 0.40\ C_4 \quad \ldots\ldots\ldots (4)$$

The 4 relations given above enable the following final results to be obtained:

$C_{41} + C_{42} + C_{43} = 0.06\ C_4$

$C_{44} = 0.18\ C_4$

$C_{45} = 0.36\ C_4$

$C_{46} = 0.40\ C_{44}$

c) From UN statistics for European Countries, it has been evaluated that the Equipment Cost (C_{44B}) constitutes 4-16% of the Capacity Cost (C_{44}) (5). Considering the local conditions of Turkey a percentage of 10% has been extimated for this purpose, leading to the following results:

$C_{44B} = 0.10\ C_{44}$

$C_{44A} = 0.90\ C_{44}$

d) The major difficulty in evaluating the shares of each factor according to local conditions has shown itself in the Materials Cost (C_{45}). This has been overcome for Turkish conditions by means of data provided by the General Directorate of Construction Materials of the Ministry of Housing and Settlement. The evaluation is given in table I.

In this table:

(i) $\overline{M}$ represents the standard in amount of materials/unit (in m^2 = 10.76 sq. ft.) of construction (6, 7).
(ii) C_M represents the unit costs of materials in monetary units (MU)/unit of construction[8]
(iii) $\overline{C_M}$ is in MU/unit (m^2) of construction
(iv)$_p$ is the share in percentage.

e) The Structure of the Finishing Costs (C_{46}) required further studies. Data provided by competent authorities and experienced contractors lead to the result that in Turkey the Labor Cost (C_{461}) forms about the 30% of the total Finishing Cost (C_{46}), leading to:

$C_{461} = 0.30\ C_{46}$

$C_{462} = 0.70\ C_{46}$

The results obtained in items (a) through (e) may shortly be shown in a tabular form as given in Table II.

3. Evaluating Savings

A parallel study taking as basis a comparison of conventional housing construction with construction by means of closed system of prefabrication gave the following results for Turkey[9].

a) Since a comparison of building systems having the same magnitude as size and area is considered, it follows that the land cost (C_1), will not be affected by the change of system.

b) According to the studies made on the construction time in Eastern Germany, it is reported that 10 months per block of 40 flats were needed in traditional brickwork while this value dropped down to 3.5 when constructing by means of heavy elements[10].

c) This results a saving of 45% in the Interest Cost (C_2). The design period of prefabrication projects is langer and it needs a high percentage of specialized personnel. However, since a high degree of typifications is used several times with minor alternations. It may therefore be concluded that the Consultation Cost (C_3) is not to be affective remarkably by prefabrication.

d) The saving obtained in the Installation Cost (C_{41}) and the Site Overhead Cost (C_{42}) may be neglected due to their very low percentage affecting the Production Cost (C_4).

e) Beside administration costs and the general costs in central office, the depreciation of the prefabrication plant and the transportation equipment must be included in the Business Cost (C_{43}) in case of prefabricated construction.

Data obtained from French[11] and German[12] standards as well as from an example of prefabrication in Turkey (Ereğli), show that due to depreciation and interest in total Construction Cost (C) increases by about 2% for a production size of 800-1000 dwellings per year.

f) A survey on manhours needed in traditional and prefabricated constructions gave as a result that following savings ($\mathcal{E}$) are realized:

Country	$\mathcal{E}$ (%)
England [13]	61
USSR [10]	54
Western Germany[14]	67
Eastern Germany	58
Denmark	40
Turkey	28

The same amount of saving will also be realized in the Labor Cost (C_{44A}).

Taking into consideration the primitive stage of construction industry in Turkey, it has been estimated that a maximum saving of 58% will possibly be reached in the future.

g) While the Machinery Cost (C_{44B}) forms about the 10% of the Capacity Cost (C_{44}), this value increases up to 40% in case of prefabrication increasing hence the Machinery Cost (C_{44B}) by at least 100% [5].

h) According to the statistics, it is seen that there is no change in the amount of cement (C_{451}) and steel (C_{452}) when using prefabrication techniques.

i) Since, in case of prefabrication, no forms and scaffoldings are used in site, a saving of 38.5% is obtained in timber (C_{453}), the rest is being used for carpentary.

j) Since no bricks are used in the prefabrication technique considered a saving of 100% is obtained in the use of this material. (C_{454}).

k) A saving of 50% is to be obtained in finishing labor cost (C_{461}) due

to flow work methods applied in prefabrication while no change will be observed in cost of materials (C_{462}).

The information given in the above items may be summerized on the right side of the dark separation line of the table III. By using the weight (in percentages) of each factor, given also in this table, the overall maximum economy is calculated.

In this table:

(i) The saving in C_{43} ($\mathcal{E}_{43}$) is obtained considering the increase of construction costs due to the depreciation of plant and steel forms. This increase is found to be 12-22% of the total construction cost (C) according to data available.

(ii) w_K^N represents the percentage of the factor C_K in the factor C_N.

CONCLUSION

This analysis gave as final result that construction by means of prefabricated components is about 9% cheaper than the conventional way of building in Turkey. A further analysis of the table III shows that the saving is mainly due to production costs. The largest saving obtained in cost of production is due to construction materials although the saving relaized in the cost of capacity and the finishing costs are not less significant. The saving due to bricks and tiles seems to be overweighing, in the cost of construction materials in Turkey. In this article the cost increase due to the depreciation of prefabrication plant and steel forms is taken as 12% of the total construction cost. Such a low value may be obtained only when prefabrication plant and forms are used to the limit of their economic lives. Otherwise this value may reach 22% which makes the application of prefabrication technique less feasible than the conventional methods of construction. The overall saving of 9% of costs may be expected to be higher in industrial countries due to low capital costs and high costs of labor. The latters influence being nullified by low productivity of labor in developing countries, the amount of saving might merely depend on cost of capital. The experience of the author in Europe showed that savings obtained by prefabrication in those countries were not significantly higher than 9% during the last decade. The importance of such a result should be taken into consideration from the national economy point of view and the consequences should be discussed in detail as soon as possible.

This model has proved to be flexible enough to work in different levels of statistical materials: It may be extended for accurate calculations, when detailed data are available; it is also applicable to the conditions of developing countries marked with scarcity and low quality of statistical material, thus providing rough approaches to the problems at preliminary stages. This model may also be used for calculations of sensibility to stipulate the influence of different factors on costs of building construction when large number of data are available. The system might, in this case, be computerized.

ANNEX I

Table I - The components of C_{45}

Materials	Unit	$\overline{M}$	C_M	$C_{\overline{M}}$	P
Bricks	No.	192	0.13	21.6	17.6
Timber	m^3	0.044	700	30.8	25.2
Steel	Kg	20	1.66	33.2	27.1
Cement	Kg	170	0.155	26.4	21.6
Tiles	No.	6.68	0.56	3.7	3.1
Aggregates	m^3	0.385	11	4.2	3.4
Lime	Kg	19.5	0.13	2.5	2.0

Table II - Evaluating the weight (w) of cost factors

C	$C_1 = 0.065\ C$		
	$C_2 = 0.030\ C$		
	$C_3 = 0.035\ C$		
	$C_4 = 0.870\ C$	$C_{41} + C_{42} + C_{43} = 0.06\ C_4$	
		$C_{44} = 0.18\ C_4$	$C_{44B} = 0.10\ C_{44}$
			$C_{44A} = 0.90\ C_{44}$
		$C_{45} = 0.36\ C_4$	$C_{451} = 0.216\ C_{45}$
			$C_{452} = 0.271\ C_{45}$
			$C_{453} = 0.252\ C_{45}$
			$C_{454} = 0.176\ C_{45}$
		$C_{46} = 0.40$	$C_{461} = 0.30\ C_{46}$
			$C_{462} = 0.70\ C_{46}$

Table III - The factors of saving

$\mathcal{E} = 0.0855$	$\mathcal{E}_1 = 0.00$, $w_1^o = 0.065$		
	$\mathcal{E}_2 = 0.45$, $w_2^o = 0.030$		
	$\mathcal{E}_3 = 0.00$, $w_3^o = 0.035$		
	$\mathcal{E}_4 = 0.081$, $w_4^o = 0.870$	$\mathcal{E}_{41} = 0.00$, $\mathcal{E}_{42} = 0.00$, $\mathcal{E}_{43} = -2.32$, $w_4^4 + w_{42}^4 + w_{43}^4 = 0.06$	
		$\mathcal{E}_{44} = 0.35$, $w_{44}^4 = 0.18$	$\mathcal{E}_{44A} = 0.50$, $w_{44A}^{44} = 0.90$
			$\mathcal{E}_{44B} = -1.00$, $w_{44B}^{44} = 0.10$
		$\mathcal{E}_{45} = 0.273$, $w_{45}^4 = 0.36$	$\mathcal{E}_{451} = 0.00$, $w_{451}^{45} = 0.216$
			$\mathcal{E}_{452} = 0.00$, $w_{452}^{45} = 0.271$
			$\mathcal{E}_{453} = 0.385$, $w_{453}^{45} = 0.252$
			$\mathcal{E}_{454} = 1.00$, $w_{454}^{45} = 0.176$
		$\mathcal{E}_{46} = 0.15$, $w_{45}^4 = 0.40$	$\mathcal{E}_{461} = 0.50$, $w_{461}^{46} = 0.30$
			$\mathcal{E}_{462} = 0.00$, $w_{462}^{46} = 0.70$

ANNEX II

REFERENCES

1. Construction Columbiana Sept. 1963 p.p. 19-22
   Prof. Miguel Fadul,
   University of Andes, Bogota, Columbia.

2. Struktur und Model eines Wohnungsbauprogrammes in den Entwicklungslandern
   SORGUO Dogan,
   Technische Hochschule Munchen Institute fur Baubetriebswissenschaft 1967.

3. Low-Cost Housing
   Bates A.
   Civil Engineering Sept. 1969.

4. Annual Bulletin of Housing and Building Statistics for Europe U. N. 1967.

5. Le Cout de La Construction de Logement en Europe
   Un Publications, ST/ECE/hov/8, Geneve 1963.

6. Yapi Malzemesi, Ayni ve Teknik Yardim (Building Materials and Subsidies)

7. Interim researchs of the General Director of Construction Materials in the Ministry of Housing and Settlement and of the State Planning Organization, Ankara-Turkey.

8. Raic Cetveli (Current Costs)
   T. C. Bayindirlik Bakanligi, Yapi ve Imar Isleri Reisligi (Ministry of Public Works) Ankara, 1967.

9. Prefabrication of Dwellings
   ARDITTI David,
   Middle East Technical University
   September 1968, Ankara.

10. Towards Industrialized Building
    International Council for Building Research Studies and Documentation, CIB, 3rd Congress in Copenhagen,
    August 1965, Elsevier Pub. Co., Amsterdam.

11. Mesken Insaatinda Prefabrikasyon (Prefabrication in Building Construction)
    BILIK Sukru,
    DSI Bulteni, Sayi No: 83-110, Ankara, February, 1968

12. Transportrationalisierung beim Bauen mit Fertigteilen
    TEIGEZKAMP, Willy
    Bau-Markt, 63 (1864), No: 34, Germany

13. Traditional Building Cost-The Target for System Building
    BISHOP, D.
    Building Research, Design Series, 42, 1966.

14. Voraussetzungen fur Wirtschaft liches Bauen mit Fertigteilen
    TRIEBEL, Wolfgang,
    Wirtschaftliches Bauen, 17 (1966), No: 1 Germany.