ECONOMIC ANALYSIS OF HOUSING DESIGN

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An economic analysis is made of two housing designs in the city of Porto Alegre (State of Rio Grande do Sul, Brazil). From the municipal approved blueprints the two designs were technically reviewed aiming at identifying possible interventions that could improve their economic performance as well as verify their principal authors' adherence to their architectural solutions. A comparison was made between the usual parametric process with the most commonly used indicators such as: construction global cost, estimation percentage services distribution participation, vertical and horizontal plans building (according to percentage participation distribution), installations and site; construction unit costs; compacity index as a key performance indicator. As conclusions, first a comparison between theoretical references and the analysed designs is presented, stressing the interventions that could be proposed to economic performance improvement for Design 1. Second, for Design 2, the repercussion on its global construction cost was analysed when the concepts of compacity index were used on the horizontal plan. In both cases the design analyses by using the shape effect have revealed that cost reductions are possible since changes could be made in the sense of reducing the number of edges and increasing the compacity index.

Key words: cost, design, estimating, housing, key performance indicators.

INTRODUCTION

This article makes a comparison between traditional Brazilian norm (ABNT-NBR 12721) cost estimation method (parametric procedures) and two other methods that are based on a building's shape. It refers only to the application of two methods in order to provide the basis for a comprehensive research. The first method deals with the amount of materials and labour costs while the second also considers the shape combined with those plan indentations that generate edges on the building; the cost impact of edges may be unperceived by the norm-based estimators, and mainly by the designers. This fact is an issue that, in the majority of projects, may lead to conflicts on the budget between designers (blueprints from office) and engineers/estimators (work on site). Literature points out the lack of designers' attention to the construction global cost (CGC) while making their decisions.

First, each of the two designs is described, then they are analysed. In Design 1 an analysis based on Mascaró's (1998) theory called Mascaró estimation method that relates design's horizontal and vertical plans, installations and temporary

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installations (such as site preparation and other related costs); after this, a study of the effect of compacity index and the balcony quality on construction costs are performed. In Design 2 an analysis of the effect of the number of edges on the general costs of construction is performed.

LITERATURE REVIEW

The comprehension of key performance indicators by designers could lead to a better understanding of impacts on construction costs of some design details. Cost analyses in early phases of the project should involve– among other measures – a search for matching the budget (within the estimation) with design propositions. The technical literature is unanimous about which design stages have the highest impact on the building's overall performance and it is the economic one that is the focus of this work (Sievert 1991; Bureau of Engineering Research 1987; Van der Mooren 1987).

Here, one of the key performance indicators is the compacity index (CI), added to the concept of economic perimeter (Mascaró 2002) that is defined as 'the perimeter of external walls passing by the internal parts of the balcony plus the perimeter of the balcony's external walls plus 50% of the external walls' and balcony's edges' (Mascaró 1998). CI is a relationship between area and perimeter, as given by the formula in row 8 of Table 1. The more compact a building is, the less cost is incurred. A circle has a CI of 100%, and square is around 85%; for rectangles, the CI starts around 60% and decreases quickly to 50% as long as the ratio between its measures increases. The study of geometric relationships goes back some decades as shown in Table 1.

Table 1: List of area comparisons by the perimeter of a closed area

Index	Equation	Author
1.Relation of shape	$\mathbf{4A/\ \pi e^2}$	Horton 1932; Haggett 1965
2. Relation of circularity	$\mathbf{4\ \pi A/P^2}$	Miller 1953
3. Relation of elongation	$\mathbf{(A/\ \pi)^{1/2}.(2/e)}$	Shumm 1956
4. Relation radial-line	$\mathbf{\sum_i (t_i\text{-}1/n)}$	Boyce and Clark 1964
5. Relation of elypsity	$\mathbf{4A/\ \pi em}$	Stoddart 1965
6. Relation of compacity	$\mathbf{A(2\ \pi f_A t^2 \eth_A)^{1/2}}$	Blair and Bliss 1967
7.Design performance	$\mathbf{100.2\ \pi(s/\ \pi)^{1/2}/c}$	March 1970
8. Compacity index	$\mathbf{2.(A\ \pi)^{1/2}.100/P}$	Mascaró 1985
9. Relation of compacity	$\mathbf{P^2/A}$	Wise 1988

Sources: 1,2,3,4,5,6, and 7 March and Steadman (1971), Martins (1999); 8 Mascaró (1985)

Notes:

A = area
C = total perimeter of the floor
S = floor area
P = perimeter of the figure
e = diameter or minor axis
m = diameter or major axis
n = number of vertices
t_i = normalized radial axes, from the centric to the vertices
t = radial axes from the centric to the small area $\eth_A$

However, those concepts are largely ignored by the majority of designers and taken for granted by the estimators because both sides operate in isolation and/or there is a lack of integration among other actors of the project's phases. Sometimes the constraint of the lot shape curbs the design towards a building's economic effectiveness owing to lack of compacity.

Another largely ignored concept is the relation of vertical and horizontal building elements. Many times designers and estimators – pressured by generalized needs of cost reductions – would like to make building cost reductions by decreasing the building’s construction area. However, as it is impossible to reduce the distance between floor and ceiling (meaning the height of walls, for instance), the real final cost will not be so impacted. Table 2 shows the impact on total costs by comparing horizontal and vertical plans in the so-called ‘Mascaró estimation method’ (MEM). According to Mascaró, vertical plans have much more cost influence than the horizontal ones.

Table 2: MEM or relationship among horizontal and vertical plans on incurred costs (adapted from Mascaró 1998)

Element	**Percentage**
Shaping horizontal plans	26.79%
Shaping vertical plans	44.84%
Installations	24.33%
Temporary installations, site preparation and other related costs	4.02%
Total	99.98%

MEM has limitations, of course, because its use is advisable only in early design phases in order to orient the designer in relation to costs. That is the purpose of this work: to get designers, in earlier design phases, to be realistic about costs, yet not unreasonably precise.

DESCRIPTION OF THE DESIGNS

Design 1

Design 1 was conceived for the staff of a state firm foundation from user needs elicited from 5000 participants. This research indicated that 125 parking spaces were needed and also indicated the required number of elevators, the amount and dimensions of rooms of each the 96 housing units, as well as the condominium infrastructure of leisure and the building of overall systems. The land lot is in Teresópolis, and has three multi-storey buildings over columns, and the dwellings are from the second floor to the ninth floor; the water reservoir and elevator installations are over these spaces. The design of each tower can be inscribed in a rectangle of 15.75 × 27.5 metres without being constrained by the lot. It presents indentation on the façade to accommodate the core of vertical circulation and thermal devices. It also has a semi-built-in balcony on the building core that can be classified as sophisticated according to Mascaró (1998). By this is meant that the design for the balcony is elaborate. The cost impact of sophistication in design is highest when compared with second and third class. According to Brazilian norms this design is classified as similar to H8/3N (eight floors, third class of finishings, i.e. not of high quality in terms of material specification). The estimated cost using parametric method reached a construction global cost (CGC) of R$5 415 486 while with Mascaró’s method it is R$5 447 072. The compacity index (CI) is 46%. The main floor plan is shown in Figure 1. As the analysis refers to estimation, details such as location in the land lot, other geometric features and other aspects are supposed unnecessary.

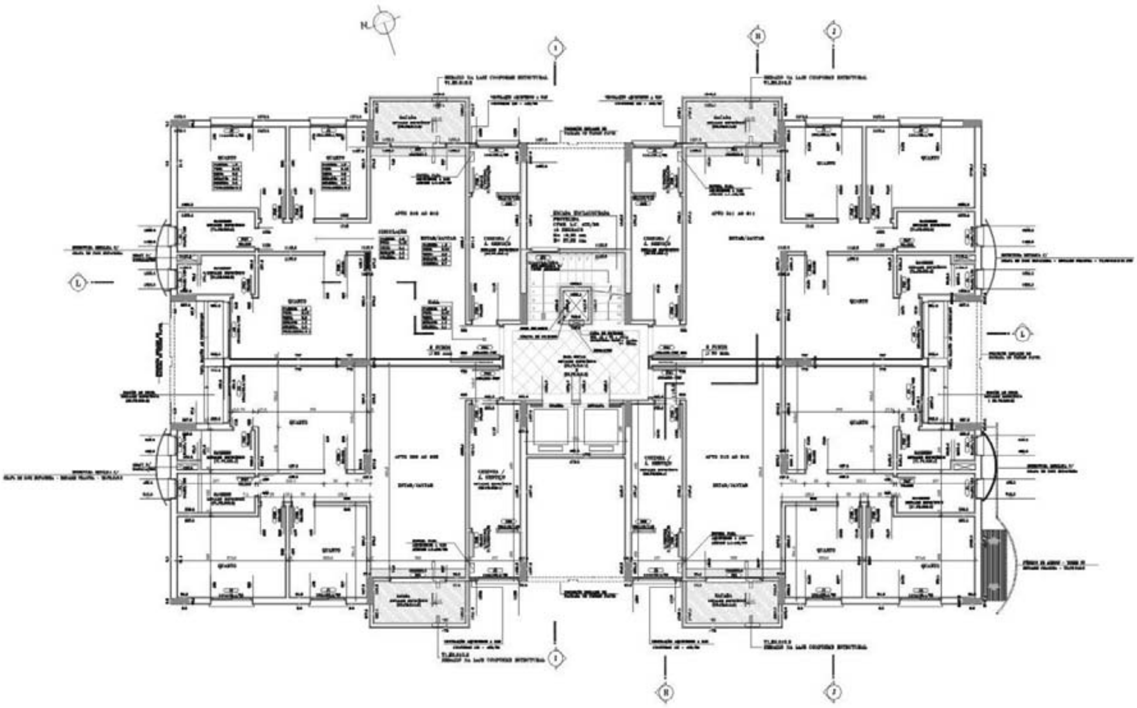

Figure 1: Design 1 main floor plan

Design 2

The conception of Design 2 was carried out by a realtor who acts in the city of Porto Alegre after consulting his/her brokers. It also is a high-rise building with an underground parking space, first floor over columns, and the dwelling units – 24 with one bedroom and 48 with two bedrooms as well as 144 parking spaces – are from the second to the thirteenth floor. According to Brazilian norms it is an H12/2N, meaning (height of) 12 floors with second class finishings. The design presents a rectangular shape in a proportion of 1:2.5 which is constrained by the lot. It also presents indentation on the façade to accommodate the core of vertical circulation. The main floor has balconies integrated with its living room. The estimated cost using parametric method reached a construction global cost (CGC) of R$6 310 000. Its CI is 64%. The main floor plan is Figure 2. As the analysis refers to estimation, details such as location in the land lot, other geometric features and other aspects are supposed unnecessary.

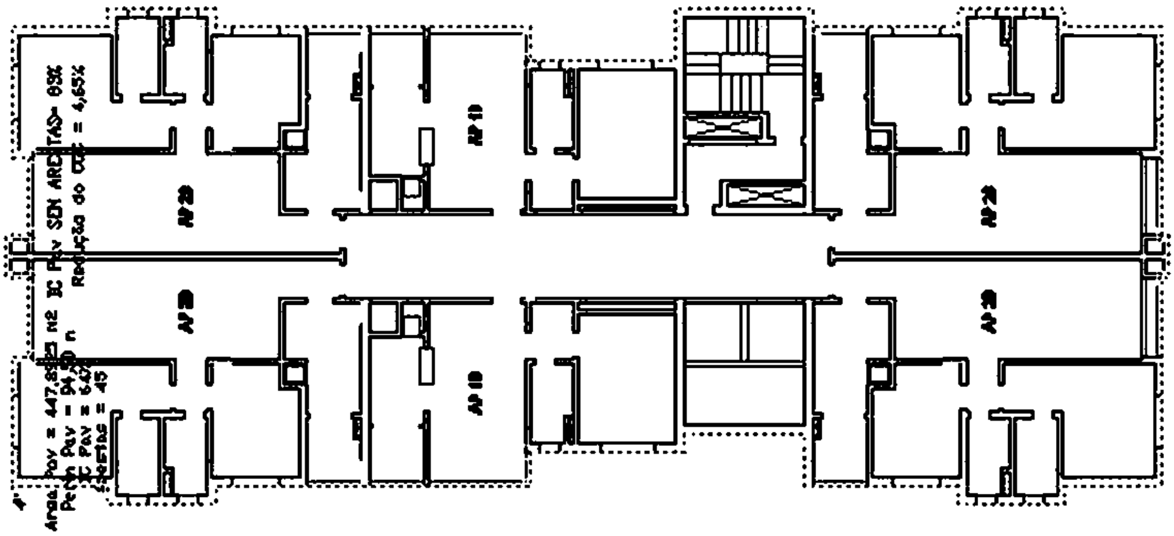

Figure 2: Design 2 main floor plan

METHOD

Design 1 analysis from economic perspective

According to Mascaró estimation method (MEM) the global cost of construction reached R$5 447 072. Table 3 shows the difference between the Brazilian norm backed methods. The overall difference is insignificant, at 0.02%.

Table 3: Differences between MEM and Brazilian norm methods

Element	% MEM	Design 1	Difference
Shaping horizontal plans	26.79%	29.8%	3.01%
Shaping vertical plans	44.84%	48.19%	3.35%
Installations	24.33%	16.92%	–7.41%
Temporary installations, site preparation and other related costs	4.02%	5.09%	1.07%
Total	99.98%	100%	**0.02%**

Following this, the influence of plan shape and the area on the total cost of the building is made using the CI (in the second column as percentage, in the third as it increases the cost also by percentage, and, in the fourth, construction costs decreasing) in eight steps named as ‘action’ in the first column. The first step is to downgrade the quality of the balcony, from sophisticated to simple, which results in lowering its construction cost. The other steps refer to eliminating the edges of the main floor plan in order to increase the CI and decrease the construction cost per square metre (CC/m^2). Table 4 shows those design actions, such as changing its rectangular-shaped plan, and in the last column is written the impact of the intervention.

Table 4: Actions on Design 1 towards CI and CC/m^2

Action	CI (%)	CI(+)%	CC/m^2 (–)	Comment
Original plan	46	None	None	None
01 Change for simple balcony	56	19.8	4.5%	Radical
02 Remove façade edges (rect. plan)	62	33.3	8.4%	Radical
03 Action 02 decreasing larger side	62	32.7	7.9%	Radical
04 Action 02 decreasing shorter side	60	30.0	6.9%	Radical

05 Keep only vertical circulation indentation + decreasing shorter side	51	10.7	2.6%	Radical
06 Keep only thermal devices' indentation + decreasing shorter side	55	17.8	4.0%	Radical
07 Keep only thermal devices' indentation + decreasing larger side	55	19.6	4.3%	Radical
08 Keep only vertical circulation indentation + decreasing shorter side	51	8.9	2.2%	Radical

In Table 4, the first column shows eight design measures from the original plan; the main design actions are listed. In the second column, the CI is calculated accordingly. In the third, the difference between the CI of the original plan and the one calculated as a result of each of the eight design actions. The fourth shows the difference between original cost per square metre and each one of the measures (variation of CI). In the last column comments are added to the final result for each of the eight design measures. Radical means a very marked effect on the external appearance of the building that could generate disagreement between the architect and the design consultant (in this case, engineer).

After presenting the results, and owing to the fact that the municipality had approved this design (ready for constructing), Option 1 was chosen. This choice reduced construction costs by 4.5%.

Design 2 analysis from economic perspective

This design was analysed by the CI under three options in which each one of the finishing external characteristics were kept as they were formerly proposed by the designer; only the effect of changes on geometric shape were used to evaluate the CI effect on the construction global cost indicated by square metres (CC/m^2). The shape option is indicated by the number of edges whose number directly affects CC/m^2. Table 5 shows these options.

Table 5: Actions on Design 2

Options	**CI (%)**	**Number of edges**	**CGC (R$x1000)**	**Savings (%)**
Original plan	64	45	6310	—
01 Keep plan area and adjust perimeter to 24 edges	70	24	6180	2.06
02 Keep plan area and adjust perimeter to 12 edges	75	12	6100	3.32
03 Keep plan area and adjust perimeter to 4 edges	83	4	6016	4.65

After presenting this Table to the realtor and the designer the decision made was to choose Option 2. The saving of R$210 000 on construction costs represented the sale price of two one-bedroom apartments or one two-bedroom apartment. The main reason for choosing Option 2 is because it impacts on the design only slightly while making large savings in construction costs. It is not a perfect decision, and that is why it is called an 'option'.

RESULTS

The comparison between theoretical references and the analysed designs in the light of compacity index, vertical/horizontal shaping plans, and the number of edges has demonstrated that simple interventions in the design phase can be proposed to increase the economic performance improvement for both designs. For Design 1, using Mascaró estimation method (MEM) in which shaping of vertical and horizontal plans were considered, a negligible error of 0.02% was incurred. It means that MEM has a high level of precision, at least for this example. Following this, the action towards CI reduction has shown many design solutions that could be used, depending on owner–designer relationships and/or interests. For Design 2, the economic impact derived from the number of edges was evident and the resulting savings were exemplified by apartment's sale price.

For both cases, the concepts of CI, vertical/horizontal shaping plans and MEM have provided the designer and owner with a clear vision of how to forecast budget conflicts with the designer and estimator. Further systematic research is called for to bring more clarification to these ideas. However, the main goal of this work is to provide two ways of balancing design propositions and their cost impacts by applying two easy and quick methods: compacity index and Mascaró estimation method.

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