Effect of Changes in Layout Shape on Unit Construction Cost of Residential Buildings

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Abstract
The shape of a building layout is the spatial attribute that defines the outline of the building. It affects the areas and sizes of vertical components such as external walls and associated finishes, windows, partitions and associated finishes, etc., as well as the perimeter detailing such as ground beams, fascias, and the eaves of roofs. The conclusions of previous studies on the cost implication of building shape have been premised on the knowledge of building morphological and geometrical characteristics, and have lacked empirical authentication. This study used empirical data to investigate the effect of layout narrowness and complexity (irregularity) on total and unit construction costs. The data used is the Saudi Arabian 'typical villa' as the base case at current prices and other variant shapes. The results of this study indicate that perimeter-to-floor ratio, unit construction cost and overall project cost are affected by variation in plan shape narrowness and complexity (irregularity). These results will assist construction professionals, especially the cost consultants, in making more objective design decisions and in giving cost advice related to plan layout for the benefits of their clients.

Introduction

Design variables have been defined as the parameters that describe a building and define its cost (Ibrahim, 2003). Kouskoulas and Koehn (1974) argued that the cost of a building is a function of many design variables including building locality, price index, building type, building height, building quality, and building technology. Brandon (1978), Ferry and Brandon (1991) and Seeley (1996) have contended the inclusion of plan shape as a design variable while Ibrahim (2003) argued that building size is also an important variable that defines a building cost. It is common to find buildings that have been designed to meet the same or similar needs costing different amounts because of differences in some of the design variables. For example, two or more buildings of the same size and quality that are to be constructed around the same location could cost different amounts. Improper and incomplete assessment of the effect of these design variables can lead to grave project consequences. Consequently, many authors have suggested further cost studies related to the relationship between various building design variables and unit construction cost (Ferry and Brandon, 1991; Seeley, 1996; Chau, 1999).

The building shape is the spatial attribute that defines the outline of the building. It affects the areas and sizes of the vertical components such as external walls and associated finishes, windows, partitions and associated finishes, etc., as well as the perimeter detailing such as ground beams, fascias, and the eaves of roofs. The key factors influencing decisions on the outline of a building shape for a proposed project include the ***shape of the site*** (plot); ***functional*** requirements such as natural lighting and good views; and ***manner of use*** such as coordination of manufacturing processes, and the forms of machines and finished products in a factory building. Despite the practical importance of providing a clear understanding of how design decisions concerning the plan shape of a building affect its construction cost, there is surprisingly little research on the relationship between plan shape and building construction costs. This paper investigated the cost implication of varying the shape of a building layout while keeping every other variable, such as height, size, quality, location, and time, constant.

In cost studies, the most commonly used units for expressing building costs are *total project cost* and *cost per square meter gross floor area* (commonly called cost per square meter GFA or *unit construction cost)* obtained by dividing total project cost by the gross floor area of the building (Seeley, 1996). *Perimeter-to-floor ratio*, defined as the ratio of the area of external wall to that of the enclosed floor area, is another useful index used for expressing building costs (Ferry and Brandon; Seeley, 1996).

Literature Review

As a rule, standard textbook analyses suggest that, "the simpler the building plan shape, the lower will be its unit construction cost" (Seeley, 1996). This is based on the knowledge of building morphology and geometrical characteristics. This lacks any empirical support. The reason adjudged for this by Seeley is that the perimeter required to enclose the same floor area is less for simple plan shapes. This implies reduced amount of perimeter elements such as external wall and associated finishes. It can therefore be inferred that since exterior walling system is a cost significant item, the building, having the smallest perimeter for a given amount of accommodation, will be the cheapest as far as these items are concerned (Ferry and Brandon, 1991). But Ferry and Brandon further argued that although circular shapes produces the smallest perimeter in relation to area, they do not provide the cheapest solution. The reasons advanced for this include difficulty in setting out the building; high cost of achieving curved surfaces; standard joinery and fittings based upon right angles which will not fit against curved surfaces or acute-angled corners, since non-right angled internal arrangements are generated; and inefficient use of site space.

Ferry and Brandon (1991) provided several analytical plan shape indices, which Chau (1999) criticized as being only a function of the plan geometry without reference to empirical data. Chau proposed a new approach which involves empirical estimation of a Box-Cox cost model. His results suggests that it is better to build a regression model that predicts how much floor area can be built with a fixed sum of money than to predict how much money is required to construct one unit of floor space. Ibrahim (2004) used regression analysis to develop such predictive models for assessing the effect of variation in building plan shape on unit construction cost. However, contrary to Chau's conclusions, Ibrahim's results confirmed the predictive powers of the existing plan shape indices and that of using some of the building parameters, especially the building perimeter and floor area and the perimeter-to-floor ratio.

Statement of problem

It is a common occurrence that a prospective building client may not be able to give enough details about the shape of the proposed building they wish to undertake and worst still, they may not appreciate the fact that variations in the plan shape has cost implications. This study essentially aims at using empirical data to investigate the cost implication of varying the shape of a building layout.

Research Question

The study aims at finding answers to the following research questions:

1. Does the shape of a building layout have any effect on its unit construction cost?
2. To what extent will the effect of changes in building layout on unit construction cost give the same amount of accommodation?

Objective of study

The objective of this paper is to explore the effect of changes in the shape of a building layout on unit construction cost.

The Population, Sample size and Research Methodology Adopted

The population of the study is the residential villas in the Dhahran Municipality in Saudi Arabia while the sample size is 200 randomly selected building permits covering five-year period (1995 – 1999). The 'typical villa' developed from the above, was defined in Shash and Al-Mullah (2002) and it formed the base case for this study.

The methodology employed involves the preparation of cost estimate, changing of design variables and analyses of the changes observed.

In preparing the cost estimates, the principles of traditional taking off were followed. However, in order to facilitate computerization for increased productivity and efficiency, a spreadsheet estimate template (model) was prepared. Thus, appropriate input data were supplied into the model, which the spreadsheet utilized in accordance with the built-in algebraic equations for each element, and from which the cost estimate satisfying the given conditions was generated. The input data are basic data that a designer can easily generate at the early stage of design development. The cost estimates which forms a good basis for sensitivity analyses were generated as output. The organization (coding system) of the cost estimate follows the Uniformat II system, which is an updated version of the original Uniformat by CSI, GSA, AACE and the Tri-Services Committee. The Uniformat II systematically follows the progress of construction, built using systematic numbering system for effective coding and communication. It contains additional levels of details compared to the MASTERFORMAT system.

The cost coefficients used were the average prevailing rates obtained from seven contracting organizations working for various pubic, semi-public and private residential clients in the Eastern province of Saudi Arabia. All the prices are in Saudi Riyals (40 Naira = 1 Saudi Riyal (SR)).

Methodology of Data Analysis and Discussion

The size of the Saudi Arabian typical villa was used as the base case (Appendix I). Variant shapes with the same size were then designed (Appendix II) and their cost estimates developed. Since all the other cost and design factors were kept constant, it was possible to measure only the effect of plan shape variation on the unit construction cost. The effect of varying the layout of the building plan on the cost per square meter GFA and the total construction cost were investigated, while keeping the amount of accommodation constant. An implicit assumption that the same configurations can be obtained from each layout considered is made. The detail investigation of the effect of plan shape on construction cost per square meter of GFA is partitioned into regular and irregular shapes.

Regular Shapes

The base case (Case A), against which the other variant cases were compared, has exterior dimensions of 15m x 20m per floor, average storey height of 3m and on two floors (see Appendix I). It has a GFA of 600m^2 (300m^2 per floor). The cost distributions amongst the various elements of the base case are represented in Figure 1 below.

It can be seen that building structure and services components respectively constitute about 68% and 27% of the total building cost while preliminaries and general requirements constitute 5%.

Two regular shapes that will yield 300m^2 per floor were considered. Buildings with exterior dimensions 10m x 30m and 5m x 60m, were designated Case B and Case C respectively (see Appendix II). The perimeter-to-floor ratios and unit construction costs for Cases A, B, and C are shown in Table 1 below.

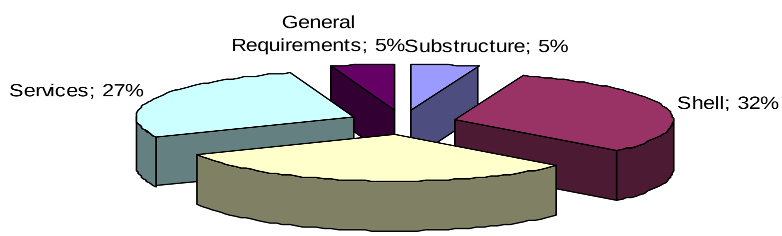

Figure 1: Elemental Distributions of Cost

Table 1: Perimeter-to-Floor Ratio and Unit Construction Cost for Layouts A, B, and C

Layout	Area of exterior cladding (m^2)	Floor area (m^2)	Perimeter-to-floor ratio	Cost per Square Meter GFA (SR)
A	420	600	0.70	3,530.81
B	480	600	0.80	3,651.24
C	780	600	1.30	4,253.42

Table 1 above shows that while the perimeter length and consequently the area of the exterior wall and associated finishes of Case B layout increased by more than 14% over those of the base case, the total cost and the unit construction cost increased by 3.4% over the base case. Likewise, the length and the area of the exterior wall of Case C layout increased by more than 85% over those of the base case. Both the total cost and unit construction cost have increased by around 20%.

Between the three layouts (Cases A, B and C) considered, the distributions of the elemental costs generally shows that the cost/m^2 are constant for the horizontal elements such as roof and floor elements. However, the elemental costs/m^2 for the vertical elements such as the exterior and interior walls together with their associated finishes and services (heating, cooling and plumbing) changed. Further analysis of the variations arising due to changes in the layout of the plan shapes indicate changes in the distribution of the cost per square meter GFA of some elements, as shown in Figure 2 below.

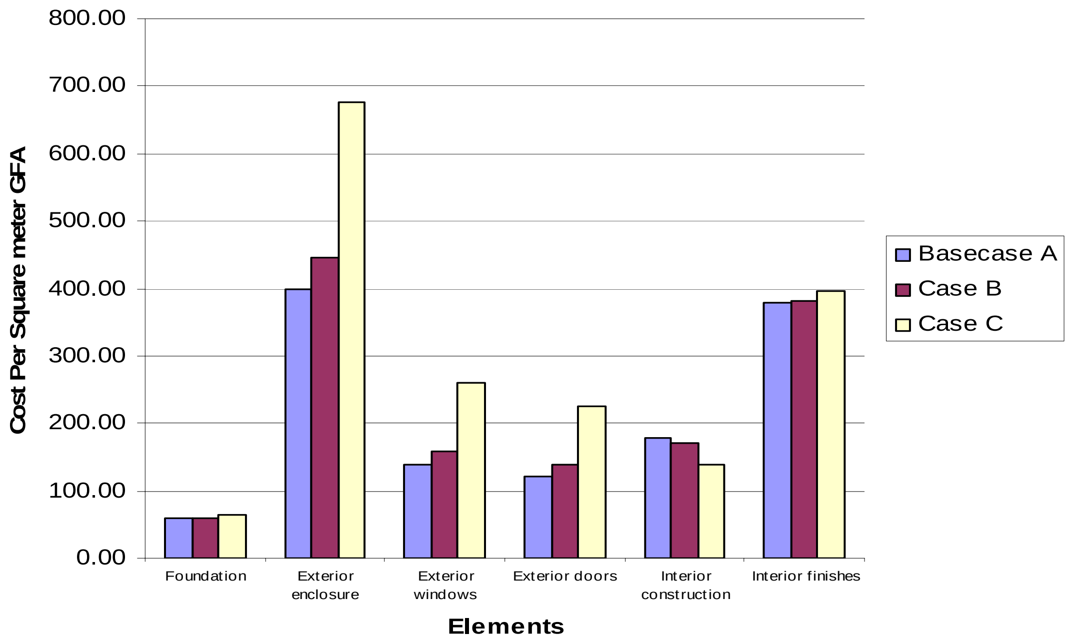

Figure 2: Variation in Elemental Cost per Square meter GFA

It can be seen from figure 2 above that the greatest variation generally occurred in the walling systems. The increased amount of exterior wall for Case C has necessitated increased exterior door and window requirements but with subsequent reduction in quantity of interior partition. However, the elemental cost per square meter GFA for interior finishes of Case C has slightly risen because of the increased inner surface of the exterior wall. The elemental cost per square meter GFA for exterior wall of Case C is still higher than those of Cases A and B by 14% and 11% respectively because of increased perimeter-to-floor ratio. However it should be noted that Case C layout is narrower and deviates more from a square shape far more than the other layouts considered.

From the foregoing analysis, it can be concluded that based on the same floor area, the comparison of the three layouts A, B and C shows that the overall costs/m^2 GFA is higher for the narrowest layout.

Irregular Shapes

Since the analyses on regular shape indicate that the exterior wall system is the most affected element arising from changes in building plan layout as reflected by the perimeter-to-floor ratio, the analysis of the irregular shapes will be restricted to perimeter-to-floor ratio and cost differentials arising therefrom. Ibrahim (2004) validated the use of perimeter-to-floor ratio as a predictor of effect of building shape on unit construction cost.

For the subsequent analyses on irregular shapes, Case A layout was still taken as the base case. However both layouts for Cases D and E (shown in Appendix II) have exactly the same floor areas as the base case, except that their outlines were made more complex. Complexity in this context is measured in terms of the irregularity of the outline. The perimeter-to-floor ratios and unit construction costs for Cases A, B, and C are shown in Table 2 below.

Table 2: Perimeter-to-Floor Ratio and Unit Construction Cost for Layouts A, D, and E

Layout	Area of exterior cladding (m^2)	Floor area (m^2)	Perimeter-to-floor ratio	Cost per Square Meter GFA (SR)
A	420	600	0.70	3,530.81
D	456	600	0.76	3,660.89
E	660	600	1.10	3,954.94

Table 2 above shows that the exterior perimeter for layout D increased by 9% over that of layout A because of increased plan shape irregularity. This resulted in almost 4% rise in unit construction cost over that of the base case. On the other hand, the exterior perimeter of layout E, with a more complicated outline compared to even Case D, increased by 57% and 45% over those of Cases A and D respectively even though they enclosed the same floor area. The reason for this increase in cost is that the perimeter-to-floor ratio of layout E is much higher than those of layouts A and D, necessitating more external walling to enclose the same floor area. This resulted in about 12% and 8% rise in unit construction cost over those of the base case and Case D respectively. This implies that increased irregularity of the shape of a building plan amplifies its unit construction cost and the total project cost.

Comparing the effect of Layout narrowness with layout Irregularity

In comparing the effect of layout narrowness with layout irregularity, all the layouts considered so far will be used but the square shape with GFA of 300m^2 (exterior dimensions = 17.32m x 17.32m) is considered as the base case. Table 3 below shows the summary of the relationship between floor area, perimeter-to-floor ratio and consequently the unit construction costs of the various building layout options considered.

Table 3: Relationship between Floor area and Cost of Exterior cladding

Layout	Area of exterior cladding (m^2)	Perimeter-to-floor ratio	Cost/m^2 GFA (SR)
Square	415.68	0.69	3,522.19
A	420	0.70	3,530.81
B	480	0.80	3,651.24
C	780	1.30	4,253.42
D	456	0.76	3,660.89
E	660	1.10	3,954.94

Table 3 above demonstrates that the more compact a plan shape the nearer it is to the square shape and the more economical it is both in terms of areas of the exterior cladding elements and the cost of the entire building. The square shape and Cases A, B, and C explain this trend. It can be discerned further that rectangular buildings having only four external corner columns (such as the square shape and layout A) are more economical than an irregular shape (such as layout E) having numerous corner columns. Seeley (1996) attributed this to the fact that an external corner column carries only a quarter of a bay. Its eccentrically loaded thereby making it less economical.

Apart from the exterior cladding, other elements that were revealed by this study as responsible for the changes in cost as a result of shape variation include setting out, excavations (for strip foundations), drainage due to extra manholes and extra length of piping needed.

Conclusions

Building shape, which is the spatial attribute that defines the outline of the building, impact the areas and sizes of vertical components such as external walls and associated finishes, windows, partitions and associated finishes, etc., as well as the perimeter detailing such as ground beams, fascias, and the eaves of roofs. It has been established to have cost implications, an understanding of which will be useful to construction cost professional. This study investigated the cost implication of varying the shape of a residential building layout while keeping every other variable, such as height, size, quality, location, and time, constant. The main findings are that:

1. The narrower the layout of a plan shape, the higher its perimeter-to-floor ratio, cost per square meter GFA and total construction cost. Stated in another way, the further a plan layout tends from a square shape, the higher the perimeter-to-floor ratio, cost per square meter GFA and total construction cost.

2. The simpler the building plan shape, the lower the cost per unit GFA for that building. Conversely, the more complex the shape of the building plan, the higher will be its overall cost based on an agreed required floor area.

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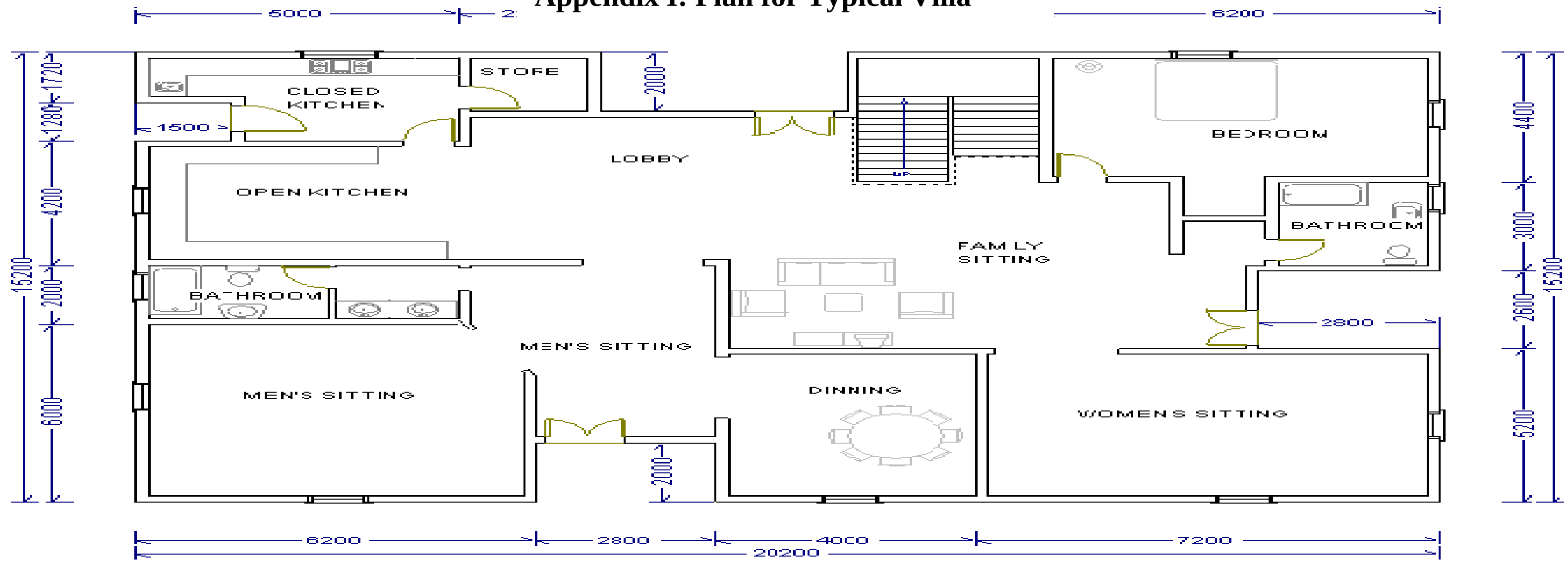
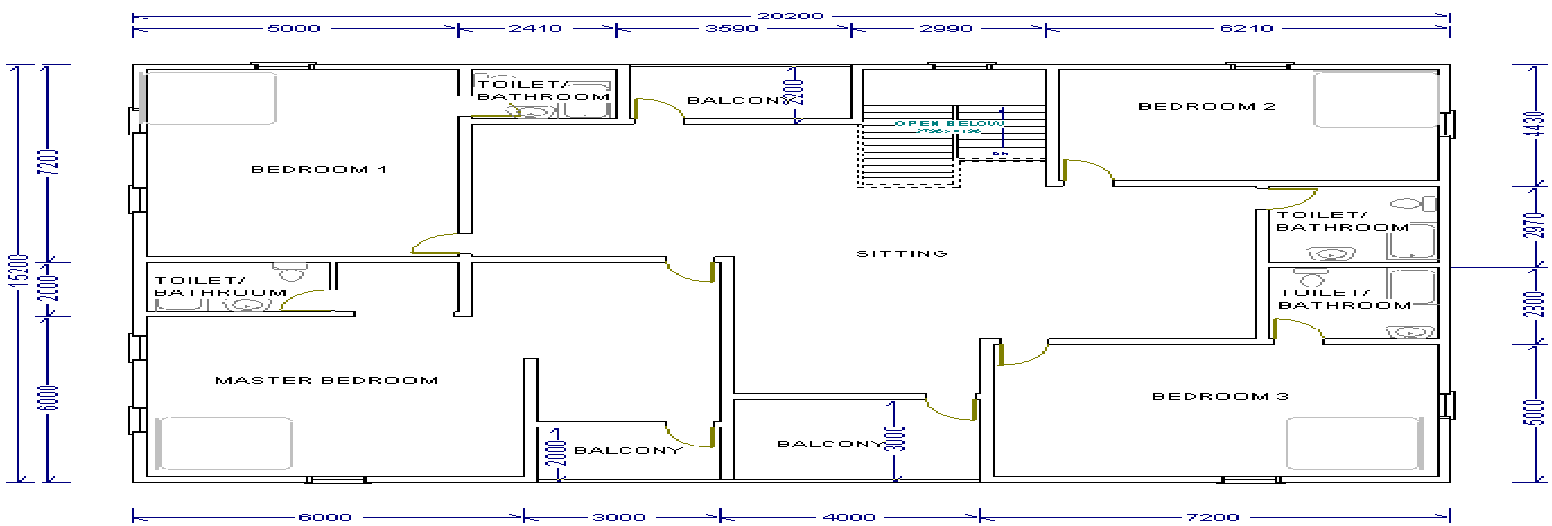
Appendix I: Plan for Typical Villa



GROUND FLOOR PLAN



FIRST FLOOR PLAN

Appendix II: Layout for Cases A, B, C, D and E