CHAPTER ONE

INTRODUCTION

1.0 Background

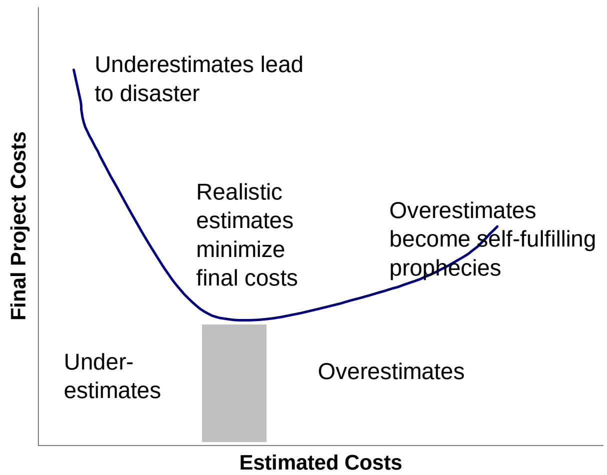
The construction process can be divided into three phases; Project conception, Project design, and Project construction. Project conception entails the recognition of a need that can be satisfied by a physical structure. The project design phase translates the primary concept into an expression of a spatial form that will satisfy the client's requirements in an optimum economic manner. The construction phase creates the physical form that satisfies the conception and permits the realization of the design. The services of Architectural/Engineering firms and contracting organizations are often engaged to assist prospective building owners in the realization of a construction facility.

The Architectural/Engineering (A/E) firms are the organizations that offer different engineering and construction support services to the public, semi-public and private sectors, in exchange for fees (Swinburne, 1980). A/E firms generally exercise the greatest influence on the cost of any building facility (Dell'Isola, 1997), and render design and many other services such as feasibility studies, construction management, cost estimation, etc. In Saudi Arabia, Al-Thunaian (1996) reported that some of the A/E firms provide cost estimation as part of their engineering and consultancy services for public, semi-public and private clients. The types of estimates prepared include feasibility, budget and design estimates. Although the estimates compare favorably with the bid prices, the estimates are prepared manually which makes them labor-intensive, costly, difficult to check and update, and thus error-prone.

A building project can only be regarded as successful if it is delivered at the right time, at the appropriate price and quality standards, and provides the client with a high level of satisfaction (Barclay, 1994). One important influence on this is the authenticity of the cost estimates prepared by the Architectural-Engineering (A/E) firms during the various phases of any building project, especially during the early phases. Often the quality of the project design, along with the ability to start construction and complete it on schedule, are dependent on the accuracy of cost estimates made throughout the design phase of a project.

Since cost has been identified as one of the measures of function and performance of a building, it should be capable of being “modeled” in order that a design can be evaluated. This will assist in providing greater understanding and possibility of prediction of the cost effect of changing the design variables by the A/E firms. Cost modeling has been defined by Ferry and Brandon (1991) as the symbolic representation of a system in terms of the factors, which influence its cost. In other words, a model attempts to represent the significant cost items of a building in a form which will allow analysis and prediction of cost to be undertaken according to changes in such factors as the design variables, construction methods, timing of events, etc. The idea is to simulate a current or future situation in such a way that the solutions posed in the simulation will generate results, which may be analyzed and used in the decision-making process of design development. The several estimating techniques used at the pre-design phase of the construction project do not seem to have any procedure to systematically account for changes in the various design variables. This often leads to inaccurate estimates. The consequences of bad estimates at the early phases include embarking on an infeasible project and rejecting a hitherto feasible project. The value of good estimating to project management is best illustrated by Freidman's curve shown in Figure 1.1 below.

Figure 1.1: The Freidman curve



Source: Daschbach and Agpar (1988)

It can be seen from the figure that both underestimating and overestimating rises with actual expenditure, and the most realistic estimate results in the economical project cost.

1.1 Statement of the problem

One of the first questions that is usually asked by any prospective client that is interested in a building a structure is 'how much will it cost?' Although the primary purpose of the figure that will be given by the designer is to provide an indication of the probable cost of the facility, it remains fresh in the mind of the client throughout the period leading to the actualization of his idea. The estimate will also provide the basis for the client's funding arrangements, budgeting and control of the construction costs.

However, history and daily life experiences present scenarios where prediction-based decisions have resulted in fiascoes, especially with regards to building projects where cost and schedule overruns are prevalent. There is a general acceptance by researchers that the level of accuracy achieved in design cost estimating is lower than desirable (Adrian, 1982; Ogunlana, 1989; Cheong, 1991; Clough and Sears, 1994; Eldeen, 1996; Seeley, 1996; Gunner and Skitmore, 1999; Ling and Boo, 2001). Accuracy in this context is defined as the deviation from the lowest acceptable tender received in competition for the project. The low accuracy reported by the researchers have been attributed to the nature of historical cost data, design data, time available for the estimate, estimating method and the expertise of the estimator.

Even though early estimates are accepted as approximations that includes some degree of uncertainty, an early cost estimate that is too high may discourage the prospective client from proceeding further with the scheme (lost opportunities) or at the least cause him to re-consider the scope of the project. Conversely, if the estimate is too low, it may result in abortive (wasted) development efforts, dissatisfaction on the part of the client (such as obtaining lower than expected returns) or even litigation.

The principal components of the cost of any construction facility include site, location and accessibility; soil and subsurface conditions; time and season; climatic conditions; wage agreements; strikes and lockouts; market prices of basic materials; availability of money; demand for construction; political and economic climates; and design style. While several of these factors could be constant for a given project, the design style could be varied in order to select the most economical option. It is in fact customary that for any one project, the designer will, in liaison with the client, consider several different options as possible economical design solution. The factors that have economic consequences in the various design options are identified and examined, and this often form the basis of selecting the most suitable and appropriate proposal for the prospective client to embark upon. However, it is particularly worrisome that there has not been sufficient research that provides clear indications of the degree to which changes in the parameters of the building (design variables) will affect its cost, while providing the same accommodation and quality of specification.

It therefore became pertinent to ask the following questions which form the basic research questions that this study attempts to provide answers to:

1. Is cost estimation practiced for residential buildings by the A/E firms in the eastern province of Saudi Arabia?
2. What are the estimating techniques used by the A/E firms for forecasting the early cost estimate for a proposed residential building?
3. What are the procedures adopted by the A/E firms in accounting for the cost of the design variables, when preparing the early cost estimates for a proposed residential building?
4. What are the effects of design variables on the cost of a residential building?
5. Comparing early estimates prepared with the eventual tender figures, how do the managers of A/E firms assess the accuracy level of estimates prepared by their firms
6. How can the current estimating system adopted by the A/E firms in accounting for the design variables in early cost estimates and the overall accuracy of cost estimates be improved?

1.2 Objectives of the Study

The principal objectives of this study are to:

1. Investigate the techniques that are used by A/E firms for forecasting the early cost estimates of residential buildings.
2. Investigate the procedures adopted by the A/E firms in accounting for design variables during the preparation of early cost estimates of residential buildings.
3. Study the effect of design variables on the construction cost of a residential building.

1.3 Significance of the Study

Estimating the cost of a building construction project is not always considered as seriously as it should be at the early stages of the design development. It is however very important as it influences the client's brief and can determine the viability or otherwise of the entire project. The characteristics of design variables could vary from location to location depending on the environmental and other circumstances that dictate the building designs. There are however, no systematic procedures for accounting for these design variables. The understanding of the effects of these design variables will, in no small measure improve the accuracy level of construction cost estimates. The study of the effect of design variables will provide results that will provide the following benefits:

1. Establish the scope and methodology of cost estimation function performed by A/E firms in the eastern province of Saudi Arabia for the benefit of the entire construction industry including prospective building clients.

2. Indicate the accuracy level of early cost estimates prepared by A/E firms, which will in turn, highlight the extent of improvement needed to improve the current techniques used.
3. Assist designers in understanding the cost implication of design variables, so that they can make more objective design decisions during the early phases of a residential building project, especially in the selection of the most economical design from several options.
4. Avail the designers with a tool for giving more objective cost advice to their clients during the early phases of a project.

1.4 Scope and Limitation

The following restrictions will be imposed on this study because of time and cost constraints:

1. The statistical sample of respondents selected to participate in the questionnaire survey was restricted to A/E firms practicing in the eastern province of Saudi Arabia. The questionnaire was administered to the entire population.
2. The structure of the questionnaire inquiry focused on cost estimation services provided by the A/E firms at the early stages of residential building projects. The choice of residential buildings is because they are the commonest and the most demanded form of construction due to their strategic importance to the social and political status of human race.

3. The empirical analysis was restricted to considerations related to residential building designs.
4. The design variables to be considered were limited to those that are Architectural in nature. Thus, detail implications of structural, mechanical and electrical engineering services were not considered in this study.
5. Only the effects of changing the design variables were measured in the empirical studies. The variables of interest in this study include Plan shape, Building average storey height, Number of floors, Circulation space and Glazed area. All the other cost factors were held constant during the simulations.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter reviews existing literatures related to the subject matter. The discussions are partitioned into four parts. The first part briefly discusses the principal origins of construction costs. The second part discusses some of the estimating techniques that are used at the early stages of design development for forecasting the probable construction cost of a building. The third part will discusses some of the rules-of-thumb on the cost implications of design variables. The fourth and last part of this chapter briefly discusses computer simulation in the light of construction industry.

2.1 Origins of construction costs

Ferry and Brandon (1991) summarized the origins of construction costs into two basic sources:

1. The owner-designer, through the owner's requirements and the design,

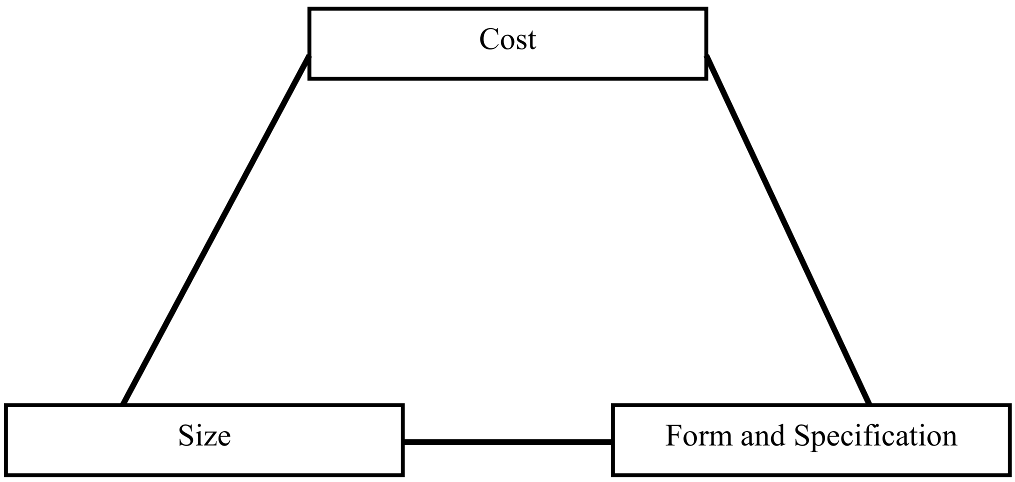
2. The contractors and subcontractors, through the competitive market and their own organizations.

It is thus expedient to examine construction costs from the perspectives of design and the construction market. Since this study is concerned with the design aspect of construction costs, only issues related to design will be discussed.

The construction client/owner is the primary originator of construction costs through his requirements and his ability to pay for them. Even though most owners may not know exactly what their requirements are, they will probably have a clear idea of their financial limitations. The designs are made to adapt to either of the conditions.

A very useful basic relationship between design and cost is shown in Figure 2.1 below.

Figure 2.1: Simplified relationship between design and cost



Although an over-simplistic view of the cost system, the sketch provides a starting point in the understanding of the complex relationships, which exist between design and cost. The triangular set of relationship illustrates that any two of the factors is a function of the remaining one. For instance, if the size, and form and specification of a building are fixed, then a certain cost will be generated for the proposed facility. Conversely, if the cost and size of a building are established (as is the case with most government yardsticks), this constrains the form and specification that can be chosen. On the other hand, if the cost and the form and quality standards of the specification are established, then the amount of accommodation is the design variable which is limited. Since one factor must be the resultant, it is never possible to declare all three in an initial brief. It is the skill of the design team in achieving the right balance between these factors that makes any project a success or a failure. The accuracy and ease of estimating exercise is highly dependent on the amount and quality of information available to the estimator.

Construction estimating involves the determination of quantity of work to be performed and the determination of the cost of doing the work. Perhaps, of these two independent processes, the most difficult and challenging is the determination of cost. Skillful determination of the cost of doing work is not limited to the knowledge of costs of labor, material, equipment and other direct costs of doing the work. It is also dependent upon the interplay of the design variables (morphology) and the estimator's choice of alternative means of construction and methods of doing the work.

2.2 Estimating techniques used at Pre-Design Stage

Estimating is a key to a successfully conceived, managed, and completed project (AACE International, 1992). This is not limited to the construction industry but rather, it is a function common to a wide spectrum of projects in which cost and time must be managed. The Association for the Advancement of Cost Engineering (AACE) International (1992) has defined *cost estimate* as 'a compilation of all the costs of the elements of a project or efforts included within an agreed-upon scope'. Collier (1987) defined a construction cost estimate as the best judgment of what a project will eventually cost. Since an estimate is prepared prior to the commencement of work, its accuracy will depend upon the skill and judgment of the estimator. Raddon (1982) defined skill as the 'accurate use of proper estimating methods', and judgment as the 'correct visualization of the work as it will be carried out'. Each estimate contains three interdependent variables:

1. Quantity
2. Quality
3. Cost

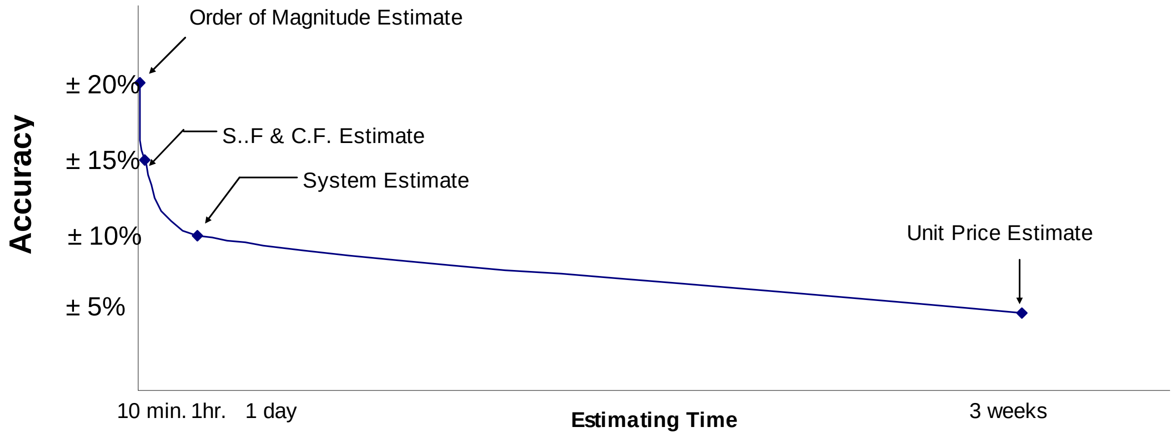
Construction documentation in the form of drawings and specifications dictates the quantities and quality of materials required, and cost is determined based on these two elements. If a specific cost or budget must be maintained, then either the quantity or quality of the components is adjusted to meet the cost requirement. The primary function of any cost estimate is to produce a forecast of the probable cost of a future project. In this way the building client is made aware of his likely financial commitments before extensive design work is undertaken, to determine the feasibility of the project or funding requirements. This will ensure the most economical choice from a list of alternative design proposals, and the control of project costs during the design phase.

Generally, pre-design estimates serve both as budgetary and planning tool. They are used for different reasons and so are made using different methods with each method providing different answers. The choice of what method to be employed is usually dictated or influenced by the purpose of the estimate, the amount of information available and/or required by the system, the time available for making the estimate, and the experience of the estimator.

The preparation of accurate early cost estimates is very important to both the sponsoring organization and the project team. For the sponsoring organization, Oberlender and Trost (2001) stressed that early cost estimates are vital for business unit decisions that include strategies for asset development, potential project screening, and resource commitment for further project development. For the project team, the performance and overall project success are often measured by how well the actual cost compares to the early cost estimates.

Although there are no universally accepted names for the different types of pre-design cost estimates, most estimators will agree that each type has its place in the construction estimating process. The type of estimate performed is related to the amount of design information available. As the project proceeds through the different phases of the design, the type of estimate changes and the accuracy of the estimate also increase. Figure 2.2 graphically shows the relationship of required time versus resulting accuracy for some four basic estimate types.

Figure 2.2: Relationship between Time and Accuracy of basic estimates types



<u>Estimating Time Vs. Accuracy</u>
(Based on a $2,000,000 building)
Source: Waier, P.R. and Linde, C.W. (1993)

The American Association of Cost Engineers defines three types of estimates. They may be known by various names and have many applications:

1. Order-of-Magnitude estimates
2. Budget estimates
3. Definitive estimates

Many techniques have been developed by researchers to forecast the probable cost of a construction project. Some of the common techniques used for the Order-of-Magnitude and Budget estimates are discussed in the following paragraphs.

2.2.1 Order-of-Magnitude Estimates

The Order-of-Magnitude cost estimating may be defined as a quick method of determining an approximate probable cost of a project without the benefit of detailed scope definition. The estimates can be completed with only a minimum of information and time. The proposed *use* and *size* of the intended structure should be known and may be the only requirements. Examples include an estimate made from cost capacity curves, an estimate using scale-up or scale-down factors, and an approximate ratio estimate. An estimate of this type would normally be expected to be accurate within +50% or -30% (AACE International 1992). The accuracy of Order-of-Magnitude estimates depends on the amount and quality of information available as well as the judgment and experience of the estimator. Users must recognize these limitations and not "hang their hats" on the resultant estimates. They may be used for:

a. Establishing the probable costs of a program budget
b. Evaluating the general feasibility of a project
c. Evaluating the cost consequences of proposed design modifications
d. Updating a previously prepared order of magnitude estimate
e. Establishing a preliminary budget for control purposes during the design phase
f. Screening a number of alternative projects so that one or more can be given a more detailed examination.

The order-of-magnitude estimate category encompasses a number of methods. Some of the more commonly used methods are End-Product (functional) Units, Floor area unit, Building volume unit, Scale of Operations, various Ratio or Factor methods, Physical Dimensions, and Parametric estimating methods.

2.2.1.1 Functional Unit Method

This method is used when the estimator has enough historical data available from experience on a particular type of project to relate some end-product units to construction costs. This allows an estimate to be prepared for a similar project when the only major difference between the projects is their size. Examples of the relationship between construction cost and end-product units are:

- The construction cost of an apartment building and the number of apartments
- The construction cost of a hospital and the number of beds
- The construction cost of a parking garage and the number of available parking spaces
- The construction cost of an electric generating plant and the plant's capacity in kilowatts.

In simple terms, this type of estimate measures the cost of a building relative to its function or use by allocating cost to each accommodation unit of the facility. The total estimated cost of the proposed building is determined by multiplying the total number of units accommodated in the building by the unit rate. The unit rate is normally obtained by a careful analysis of the unit costs of a number of fairly recently completed buildings of the same type, after making allowance for differences of cost that have arisen since the buildings were constructed (inflation) and any variations in site conditions, design, state of the market, etc. (Smith, 1995). These may be carried out using building cost indices and cost planning techniques.

Seeley (1996) commented that the weaknesses of this method lies in its lack of precision, in the difficulty in making allowance for a whole range of factors such as the shape and size of the building, form of construction, materials, finishings, etc. and that the accuracy is low for majority of purposes. The use of this technique is limited to public projects and/or very early stages of project definition where very little design has been undertaken. Nevertheless, presenting cost in this format is most times more meaningful to decision-makers and the public who may have limited knowledge of construction.

2.2.1.2 Floor Area Unit Method

The commonest used unit-cost estimate is the *cost per square meter of floor area estimate.* The method involves measuring the total floor area of all storeys between external walls without deductions for internal walls, lifts, stairwells, etc. By multiplying the historical square-meter cost by the calculated square meter of floor area for the proposed building, a pre-construction preliminary cost estimate for the building can be determined.

Although the calculation is quick and straightforward, the major drawback is in determining a suitable rate. Other drawbacks of this method include the imprecision in making allowances for plan shape, storey heights, number of floors and changes in specification. The unit cost for many building types and for different quality grades are available in standard published sources.

2.2.1.3 Building Volume Unit Estimate

Similar to the cost per square meter estimate is the *cost per cubic meter estimate*. This type of estimate relates the cost of a building to its volume. The cubic content of the building is obtained by multiplying the length, width and height (external dimensions) of each part of the building, with the volume expressed in cubic meters. Some 200 – 250 mm is added to the height to cater for the foundation work and the method for obtaining the height of the building depends on the method of construction and the nature of occupation. Historical data are collected regarding the cost as a function of the enclosed volume of the building. Cost-per-cubic-meter estimates are rather unreliable unless virtually identical buildings are compared, as there is no much relationship between the volume of a building and its cost. They may however be used for structures such as warehouses, which have varying floor heights and for which the square meter method tend to be unreliable because of the differences in floor heights.

A primary weakness of this method is its deceptive simplicity. It is quite a simple operation to calculate the volume of a building, but the difficulty lies in the incorporation of the several design factors into the cubic unit-rate. This method fails to make allowance for plan shape, storey heights and number of storeys, and column spacing, which all have influence on cost, and cost variations arising from differences such as alternative foundation types are difficult to incorporate in single unit-rate (Seeley, 1996). The cubic content also does not give any indication to a building client of the amount of usable floor area, and it cannot readily assist the architect in his design of a building, as it is difficult to forecast quickly the effect of any change in specification on the cube unit price rate.

2.2.1.4 Enclosed Area Estimate

This type of estimate is based on the area of all the horizontal and vertical planes of the building. The principal objective of the method is to devise an estimating system, which, whilst leaving the type of structure and standard of finishings to be assessed in the price rate, would take into account:

1. Building shape
2. Total floor areas
3. Vertical positioning of floor areas in the building
4. Storey heights of buildings
5. Extra cost of sinking usable floor area below ground level.

When using this technique, the following works have to be estimated separately (Seeley, 1996):

1. Site works such as roads, pats, drainage service mains and other external works.
2. Extra cost of foundations, which are more expensive than those normally provided for the particular type of building
3. Sanitary plumbing, water services, heating, electrical and gas services and lifts
4. Features which are not general to the structure as a whole, such as dormers, canopies and boiler flues
5. Curved works.

In this type of estimate, the area of the floors is added to the interior areas of the walls. The historical cost per the sum is collected and the unit cost is multiplied by the areas of floors and walls of the proposed building to yield the total cost estimate of the project. Using this method involves applying various factors for floor areas depending on the location of the floor and weightings to obtain the storey enclosure units. Its proponents argue that prices thus obtained are much closer to tender figures than using the methods earlier described (Seeley, 1996). However, the method has had little application in the industry due to the volume of work involved and the dearth of published cost data for its application.

2.2.1.5 Scale of Operations Method

This method uses historically derived empirical equations to obtain an estimate of approximate cost for different sizes of the same type of industrial facility. This system is sometimes known as the six-tenths rule. A common form of this equation is:

$$C_2 = C_1 * \left(\frac{Q_2}{Q_1} \right)^X \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \qquad (2.1)$$

Where C_2 = Cost of desired plant or piece of equipment

C_1 = Known cost of plant or piece of equipment

Q_2 = Capacity of desired plant or item

Q_1 = Capacity of known plant or item

X = Constant, usually in the range of 0.6 to 0.8

This mathematical relationship reflects the non-linear increase in cost with size, and shows economy of scale where the construction cost per unit capacity decreases as the project size increases (AACE International, 1992).

2.2.1.6 Ratio or Factor Methods

This type of estimating method is best used for projects containing a single key or predominant cost component that makes up a major portion of the total cost of the project, such as the purchased equipment for the building. Examples of such projects are heavy engineering and process plants like refineries and foundries. The factor estimate develops factors for each component as a function of a predominant cost. The theory behind factor estimating is that components of a given type of project will have the same relative cost function of a key or predominant cost for each and every project; for example, for a steel mill, the processing equipment often dictates the cost of the building components. Generally, types of factored estimates can be based upon the cost per average horsepower, cost per square meter, cost per ton, etc., of major equipment or component.

The factor estimate is also based on historical data. The historical unit costs are multiplied by the physical parameter measurements/factors of the proposed building (either one factor for all equipment, or different factors applied to individual components) to arrive at an approximate cost for the entire project.

Many specialized Ratio or Factor methods are available to the estimator. Several of those typically used are described below.

Multiple of Equipment Cost

This method is commonly used in construction process and chemical plants where the cost of the specialized equipment makes up a major portion of the total project cost. Approximate project costs may be estimated by totaling the cost of all major items of equipment and then multiplying this sum by a single ratio obtained from either historical data or other reliable sources. The estimate should be accurate from +15% to -30% (AACE International, 1992).

Lang Factors

Lang Factors are simply standard multipliers (factors) for use in specific situations. Sample factors are (AACE International, 1992):

3.10	For solid process plants
3.63	For solid fluid plants
4.74	For fluid process plants

Hand Factors

Hand factors expand on the Lang factors approach by using the individual components of permanent equipment or systems. Each factor converts the cost of the equipment item to its share of total construction cost (including labor, materials, construction equipment, overhead and distributables). When all line items are factored and added together, the estimator has a total estimated cost for the project. Some of the factors proposed for process plant equipment are (AACE International, 1992):

8.5	For electric motors
4.8	For instruments
4.0	For fractionating columns, pressure vessels, pump, etc.
3.5	For heat exchangers
2.5	For compressors
2.0	For centrifuges

2.2.1.7 Parametric Estimating Method

This type of estimate, as the name implies, is based on certain parameters that reflect the size or scope of the project. Parametric estimates are commonly used in the building construction industry for preparing approximate estimates. These estimates are usually prepared after the preliminary design phase is complete and the project's key features and dimensions have been defined. Various trade sections and cost elements that show the total cost of each of these elements such as concrete, masonry, plumbing, etc. for the reference project are listed. These cost elements are each related to one of the previously listed parameters. The relation is simply obtained by dividing the total parameter (component) cost by the physical parameter (area or volume) in order to obtain the cost per unit of the parameters (AACE International, 1992). For example, structural steel cost may be related to the gross area supported, and dry-wall cost to interior area.

These unit costs are then multiplied by the physical parameter measurements of the proposed building to obtain its total cost estimate. Care should be taken in choosing the parameters for the old and proposed buildings, as they must be the same. The major cost areas for both buildings must also be the same; in other words, this method can only be used for similar projects.

Parametric estimates can be more accurate than other order-of-magnitude estimates because the project can be broken down into more detail. In this method of estimating, all project costs are related to parameter costs of a reference (similar) project.

2.2.1.8 Systems (or Assemblies) Estimate

This type of estimate is usually prepared after the architect completes the design development plans, as a budgetary or planning tool during the planning stages of a project. It involves breaking down the total building into the basic parts or trades, and reflects how a building is constructed. Twelve "Uniformat" divisions organize building construction into major components that can be used in Systems Estimates (Waier and Linde, 1993). These Uniformat divisions include:

Division 1 – Foundation

Division 2 – Substructures

Division 3 – Superstructures

Division 4 – Exterior closure

Division 5 – Roofing

Division 6 – Interior construction

Division 7 – Conveying systems

Division 8 – Mechanical

Division 9 – Electrical

Division 10 – General conditions and profit

Division 11 – Special

Division 12 – Site work

Each division is further broken down into systems, with a component appearing in more than division and each division may incorporate more than many different areas of construction, and the labor of different trades.

A great advantage of the Systems estimate is that the estimator/designer is able to substitute one system for another during the design development and can quickly determine the cost differential. The owner can then anticipate accurate budgetary requirements before final details and dimensions are established.

2.2.1.9 Range Estimating

All the previously discussed estimating methods utilize a single point approach in determining the cost of a proposed project. However, an estimate by definition is uncertain and no matter how much experience goes into developing this single point estimate, it is highly unlikely that the actual value will fall precisely at the stipulated number. One way of recognizing and evaluating the uncertainty of an estimate is through the use of *range estimating.* Range estimating has the objective of setting out a range of possible project costs or probabilities of various projects costs within this range. In other words, this method indicates how much higher or lower the actual cost varies from the single point estimate.

The range estimating does not limit itself to an estimate of a single cost for each work package or phase. Instead, the use of the process states a target cost, the lowest estimated cost, a highest estimated cost, and a confidence limit or likelihood that the actual cost will be equal to or less than the target cost.

Adrian (1981) argued that knowledge of the range of project costs and the likelihood of overrunning a single cost helps the designer to equate risks; to budget for contingencies or to redesign aspects of the project to decrease the potential range of costs. DeGoff and Freidman (1985) commented that it represents more accurately the probabilistic nature of estimating.

2.2.1.10 Cost Modeling

Cost modeling is a more modern method that can be used for forecasting the estimated cost of a proposed construction project. It involves the construction of mathematical models to describe project costs. A model is a mini representation of reality. Models can be constructed to cover real life situations provided some facts are available to trace the detail of the existing problem (Rowe, 1975). A model is built from currently available data and from factors related to previous performance. This information is analyzed in model form so that the trends can be correlated. Predictions can then be made about the future. The use of computer has allowed these numerical methods such as statistical and operation research techniques to be applied to the forecasting of construction costs. These models attempt to formulate better representation of construction costs than the other methods, by trying to discover the true determinants of construction costs. Typical examples include the use of multiple regression and simulation analyses by Bozai

1981, Al-Asfoor 1993, Eldeen 1996, Horner and Zakieh 1996, Al-Momani 1996, Ranasinghe 1996, and Williams 2002.

Types of Cost Models include:

1. Designers' cost models – which uses models of previously completed buildings on which to attach estimates of future costs.
2. Constructors' or production models – which seek to model the process of construction rather than that of the finished structure.
3. Mathematical models – which have been developed by seeking to identify variables that best describe cost. Examples include empirical methods which are base on observation, experience and intuition such as the development and presentation of bills of quantities which attempts to model the physical appearance of a building and construction methods in terms of descriptions and dimensions. Other examples include regression analysis; a technique that determines the mathematical model which best describes the data collected in terms of a dependent variable i.e. the estimate. Another example is a simulation model, which seeks to duplicate the behavior of the system under investigation by studying the interaction of its components. In this way it copies the process involved and seeks, through a better understanding, to improve the quality of the estimate.

Cost modeling uses several different techniques, the choice of which depends upon many different factors such as user's familiarity and confidence with the results expected and achieved. Some of the techniques have become known as single-price methods, even though in some cases limited number of cost descriptors or variables is used. All the methods require access to a good source of reliable information and cost data if desired results are to be achieved. The classification of cost models

2.2.2 Budget Estimates

Budget estimates are prepared with the help of flow sheets, layouts, and equipment details. In other words, enough engineering must have taken place to further define the project scope. An estimate of this type is normally expected to be accurate within +30% or -15% (AACE International, 1992).

Budget estimates are also called "design development", "semi-detailed" "appropriation" or "control" estimates. Since the budget estimate is more definitive than the order-of-magnitude estimate, it is better suited for determining project feasibility and establishing definitive budgets. The accuracy and usefulness of a budget estimate depends, to a large extent, on the amount and quality of information available.

2.3 Design Variables

A 'design variable' may be defined as the parameter or unit of a building design that can be kept constant in a particular case, but which may be varied in different cases even while providing the same accommodation. Examples include plan shape, storey height, number of floors, circulation space, mechanical and electrical engineering services, etc. Kouskoulas and Koehn (1974) argued that the cost of a building is a function of many variables, and a set of independent variables should be selected that describe a project and define its cost. Such variables should be measurable for each new building project. Kouskoulas and Koehn identified the following independent variables that define the cost of a building: building locality, price index, building type, building height, building quality, and building technology.

Brandon (1978) identified the following as suitable descriptors of building form: Plan Shape Index (which represents any plan shape of building to a rectangle having an area and perimeter identical to the building it represents); Number of Storeys; Boundary Coefficient (which represents the extent of the internal divisions of floor area by expressing the perimeter of all rooms as a ratio with the gross floor area); Average Storey Height; Percentage of Glazed Area; and Plan Compactness. Swaffield and Pasquire (1996) identified percentage of glazed wall area; perimeter length; total building height; volume of plant rooms and services cores; and volume of air handled by HVAC systems, as descriptors that may be useful for determining the Mechanical and Electrical (M&E) services cost.

The major design variables are now discussed below.

2.3.1 Building Plan Shape

The building shape is the spatial attribute that defines the outline of the building. It impart the areas and sizes of the vertical components such as 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. There is surprisingly little research on the relationship between plan shape and building construction costs, despite its practical importance in providing a clearer understanding of how design decisions concerning the plan shape of a building affect its construction cost.

Standard textbook analyses suggest that as a general rule, 'the simpler the plan shape, the lower will be its unit cost' (Seeley, 1996). The rationale is that a building with a simple plan shape uses less external wall to enclose the same floor area and that the external wall is a very cost significant element. Thus, it would seem obvious that 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). However, Ferry and Brandon consequently argued that the shape that has the smallest perimeter in relation to area is the circle, which does not often provide the cheapest solution for the following reasons:

1. Difficulty in setting out the building

2. High cost of achieving curved surfaces, especially those incorporating timber or metalwork
3. Circular buildings hardly produce efficient utilization of internal space, as odd corners are generated between partitions and exterior walls
4. Since non-right angled internal arrangements are generated, standard joinery and fittings which are based upon right angles will not fit against curved surfaces or acute-angled corners
5. Inefficient use of site space

It is important to note that although the simplest plan shape (a square building) will be the most economical, it would not always be a practicable proposition resulting from the ***shape of the site*** (plot), ***functional*** requirements such as natural lighting in buildings like a school or a hospital, or good views in hotels and ***manner of use*** such as coordination of manufacturing processes and the forms of machines and finished products in a factory building. Although the square-shaped building is generally accepted to be the most cost-effective because of its reduction in cost of vertical components and the lowest area of external wall for heat loss calculations, Ferry and Brandon (1991) advised cautious generalizations of the rule, especially with regards to modern buildings and environmental factors.

Other probable theoretical support for the above textbook assertion is that "as a building becomes longer and narrower or its outline is made more complicated and irregular, so the perimeter/floor area ratio will increase, accompanied by a higher unit cost (Seeley, 1996). Irregular and circular shapes will result in increased costs because setting out, siteworks, form design and drainage works are all likely to be more expensive.

The *Perimeter/Floor ratio* is calculated by dividing the external wall area (inclusive of doors and windows) by the gross floor area. It is a means of expressing the planning efficiency of a building, and it is influenced by the plan shape, plan size and storey heights. We have seen that the plan shape directly conditions the external walls, widows and external doors – which together form the building envelope or enclosing walls. Different building plans can be compared by examining the ratio of the areas of enclosing walls to gross floor area in square meters. The lower the wall/floor ratio, the more economical the proposal will be (Seeley, 1996). A circular building produces the best wall/floor ratio, but the saving in quantity of wall is usually more than offset by the lowered output, by between 20 to 30 per cent (Seeley, 1996).

Some analytical work undertaken to measure the cost efficiency of a building shape were provided by Ferry and Brandon (1991) and summarized below:

2.3.1.1 **Wall to floor ratio** (WF) is defined as the ratio of the area of external wall to that of the enclosed floor area, i.e.

$$WF = \frac{W}{F} \qquad (2.2)$$

Where W is the area of external wall and F is enclosed floor area. The larger the value of the index, the more complicated the shape

(Moore, 1988). Hence, F x WF = W. The floor area multiplied by the WF gives the area of external wall.

Perhaps, this is the most widely used of all the efficiency ratios but it can only be used to compare buildings having similar floor areas and does not have an optimum reference point such as those below.

2.3.1.2 **Cooke's shape efficiency index** (JC) is defined as the ratio of the perimeter of a floor plan (P) to the perimeter of a square floor plan with the same floor area (A), i.e.

$$JC = \frac{P}{4\sqrt{A}} - 1 \qquad (2.3)$$

The larger the value of this index, the more complicated the shape (Chau, 1999). A formula, which relates any shape to a square that would contain the same area and thus providing a reference point for shape efficiency is given as:

$$\frac{P - P_S}{P_S} x100\% \qquad (2.4)$$

Where P = perimeter of building, Ps = perimeter of square of the same area.

2.3.1.3 **Plan compactness ratio** (POP) is defined as the ratio of the perimeter of a circular floor plan (P) to the perimeter of a floor plan with the same area (A). This index was developed at Strathclyde University and is given as:

$$POP = \frac{2\sqrt{\pi A}}{P} \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \qquad (2.5)$$

The smaller the value of the index, the more complicated the shape (Chau, 1999). In this case, the reference point is the circle (a square would have a POP ratio of 88.6% efficiency and yet it is probably the best cost solution in initial cost terms).

2.3.1.4 **Mass compactness or VOLM ratio**: uses a hemisphere as the point of reference for considering the compactness of the building in three dimensions.

$$\frac{2\pi\left[\left(\frac{3V}{2\pi}\right)^{\frac{1}{3}}\right]^2}{S} x100\% \quad . \quad .. \quad .. \quad .. \qquad (2.6)$$

Where V = volume of hemisphere equal to volume of building, S = measured surface area of the building (ground area not included).

2.3.1.5 **Rectangular index**, also called **Length/breadth index** (LBI) is defined as the length to breadth ratio of a rectangle with the same area A and Perimeter P as the building.

$$\frac{P+\sqrt{P^2-16A}}{P-\sqrt{P^2-16A}} \quad .. \quad .. \quad .. \quad .. \quad .. \qquad (2.7)$$

In this index, any right-angled plan shape of building is reduced to a rectangle having the same area and perimeter as the building. Curved angles are dealt with by a weighting system. The advantage here is that the rectangular shape allows a quick mental check for efficiency. The larger the value of the index, the more complicated the shape.

2.3.1.6 **Plan/Shape Index** is a development of the previous index to allow for multi-storey construction.

$$\frac{g+\sqrt{g^2-16r}}{g-\sqrt{g^2-16r}} \quad .. \quad .. \quad .. \quad .. \quad .. \qquad (2.8)$$

where g = sum of perimeters of each floor divided by the number of floors, and r = gross floor area divided by the number of floors.

In effect, the area and perimeters are averaged out to give a guide as to the overall plan shape efficiency.

It should however be borne in mind that all the indices discussed above consider only those elements that comprise the perimeter of the building, or in the case of VOLM the perimeter and roof. Furthermore, the repercussions of shape on many other major elements are great. For example, wide spans generated by a different plan shape may result in deeper beams, which consequently demand a greater storey height to offer the same headroom, and thus will affect all the vertical elements. These implications need to be reflected in any future models.

Chau (1999) subsequently criticized that most of the existing plan shape indices are based on the geometry of the plan without reference to empirical data. He 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. The data used for his study were obtained from a quantity surveying practice in Hong Kong and are related to buildings completed in various parts of Hong Kong at different times. The flaws of this research however, include the use of different project types with widely varying characteristics in terms of size, components and specifications such that it becomes difficult to precisely measure the impact of shape variation on unit cost due to the interplay of cost factors other than shape.

2.3.2 Size of Building

The size of a building indicates the physical magnitude of total accommodation provided by the building. Generally, total project costs increases as the building size increases but increases in the size of buildings usually produce reductions in unit construction cost, such as cost per square meter of gross floor area (Seeley, 1996). The main reason for this is that on-costs (overhead costs) do not rise proportionately with increases in the plan size of a building. Similarly, certain fixed costs such as transportation, erection and dismantling of site office accommodation and compounds for storage of materials and components, temporary water supply arrangements and the provision of access roads, may not vary appreciably with an extension of the size of building and will accordingly constitute a reduced proportion of total costs on a larger project. Thus, a larger project is usually less costly to build because the wall/floor area ratio reduces with increasing size. With high-rise buildings, a cost advantage may accrue due to lifts serving a larger floor area and greater number of occupants with an increased plan area.

2.3.3 Average Storey Height

The storey heights of buildings are mainly determined by the requirements of the use to which the building will be put. Variation in storey heights cause changes in the cost of the building without altering the floor area, and this is one of the factors that make the cubic method of approximate estimating so difficult to operate when there are wide variations in the storey height between the buildings being compared. The main constructional items, which would be affected by a variation in storey height, are walls and partitions, together with their associated finishings and decorations. There will also be a number of subsidiary items, which could be affected by an increase in storey height, as follows:

1. Increased volume to be heated which could necessitate a larger heat source and longer lengths of pipes or cables.
2. Longer service and waste pipes to supply sanitary appliances.
3. Possibility of higher roof costs due to increased hoisting.
4. Increased cost of constructing staircases and lifts where provided.

5. Possibility of additional cost in applying finishings and decorations to ceilings, sometimes involving additional scaffolding.
6. If the impact of the increase in storey height and the number of storeys is considerable, it could result in the need for more costly foundations to support the increased load.

According to Seeley (1996), one method of making a rough assessment of the additional cost resulting from an increase in the storey height of a building may be to work on an assumption that the vertical components of a building in the form of walls, partitions and columns account for certain percentage, say thirty per cent, of the total costs. For example;

Estimated cost of building = SR 3,000,000

Estimated cost of vertical components

Thirty per cent of SR 3,000,000 = SR 900,000

Proposal to increase storey heights from

2.5m to 2.8m: increased cost would be

$\frac{0.30}{2.50} x100xSR900,000$ = SR 108,000

It would however, be necessary to consider the possible effect of some or the entire subsidiary items previously listed if the increase in storey height is substantial.

2.3.4 Number of storeys

Closely related to the average storey height of a building is the number of storeys. Tan (1999) highlighted three reasons why illustration of the relationship between construction cost and building height will be useful. First, there is the question whether the unit construction cost rises with building height and, if so, the extent of the increment. This question has clear profit implications when one is considering whether to build low-rise or high-rise buildings. Indirectly, the ubiquity of high-rise buildings in the Central Business District reflects a high degree of capital-land substitution in response to land scarcity. It appears that, within the calculus of profitability, the unit cost of construction does not rise substantially with building height. Secondly, the variation in construction cost with floor level for a standard building across cities provides an indirect measure of relative productivity. Alternatively, the variation may be compared over time for a particular city as an indirect measure of productivity change. Thirdly, it is useful to know the causes of the variation of construction cost with building height to control costs or improve the productivity of high-rise construction.

In the United States, Clark and Kingston (1930) analyzed the relative costs of the major components of eight office buildings from 8 to 75 storeys on a hypothetical site. In general, unit building cost tended to rise moderately with building height. In contrast, Thomsen (1966) reported that, except for the lower floors, the unit office building cost was almost constant when building height was varied. However, since details of the simple simulation study were not reported, Thomsen’s result has to be interpreted with care. In the UK, Stone (1963) also reported a moderate rise in unit building cost with building height for blocks of flats and maisonettes in London and the provinces. Similarly, Seeley (1996) quoted a Department of the Environment (1971) study, which reported that the cost of local authority office blocks rose `fairly uniformly by about two per cent per floor when increasing the height above four storeys.’ On balance, it appears that unit construction cost tends to rise with building height. On the theoretical side, Thomsen (1966), Ferry and Brandon (1991), Schueller (1986) and Seeley (1996) provided several technological reasons and, without doubt, implicitly assumed or held constant relevant institutional factors. Empirically, the Department of the Environment’s (1971) finding that unit construction cost rise of about two per cent per floor for office blocks appears to be a reasonable average.

Ferry and Brandon (1991) provided the following concise set of reasons on the characteristics of building height; “Tall buildings are invariably more expensive to build than two- or three-storey buildings offering the same accommodation, and the taller the building the greater the comparative cost… What are the reasons for this? Firstly, the cost of the special arrangements to service the building particularly the upper floors… Secondly, the necessity for the lower part of the building to be designed to carry the weight of the upper floors. . . . Also the whole building will have to be designed to resist a heavy wind loading . . . Thirdly, the cost of working at a great height from the ground when erecting the building. . . . Fourthly, the increasing area occupied by the service core and circulation”.

Constructional costs of buildings rise with increases in their height, but these additional costs can be partly offset by the better utilization of highly priced land and the reduced cost of external circulation works. Private residential blocks are generally best kept low, for reasons of economy, except in very high cost site locations where luxury rents are obtainable. In similar manner, office developments in tower form are more expensive in cost than low rise, but provided the tower has large gross floor area per floor, the rent obtainable may offset the additional cost. Seeley (1996) provides the following general observations relating to increases in the number of storeys:

1. It is sometime desirable to erect a tall building on a particular site to obtain a large floor area with good day lighting and possibly improved composition of buildings.
2. The effect of the number of storeys on cost varies with the type, form and construction of the building.
3. Where an addition of an extra storey will not affect the structural form of the building, then, depending upon the relationship between the cost of walls, floor and roof, construction costs may fall per unit of floor area.
4. Beyond a certain number of storeys, the form of construction changes and unit costs usually rise. The change from load-bearing walls to framed construction is often introduced when buildings exceed four storeys in height.

5. Foundation cost per m^2 of floor area will fall with increases in the number of storeys provided the form of the foundations remains unchanged. This will be largely dependent upon the soil conditions and the building loads.
6. More expensive plant, such as tower cranes and concrete pumps, are required for the construction of high-rise buildings.
7. Means of vertical circulation in the form of lifts and staircases tend to be increasingly expensive with higher buildings, although fairly sharp increases in costs are likely to occur at the storey heights at which the first and second lifts become necessary.
8. As a general rule, maintenance costs rise with an increasing number of storeys, as maintenance cost becomes more expensive at higher levels.
9. Heating costs are likely to fall as the number of storeys increases and the proportion of roof area to walls increases. Heating costs are influenced considerably by the relationship between the areas of roofs and walls, as roofs are points of major heat loss. However, the services and associated equipment become more sophisticated and costly with high-rise buildings, and their ducting can also increase costs.
10. Fire protection requirements increase with height as fire-fighting equipment becomes more sophisticated, involving the use of wet or dry risers and possibly sprinklers.
11. Fees of specialist engineers will probably be incurred for the design of foundations and frame, mechanical and electrical services and fire fighting equipment.

12. As the number of storeys increase, both the structural components and circulation areas tend to occupy more space and the net floor area assumes a smaller proportion of the gross floor area, thus resulting in a higher cost per m^2 of usable floor area.

It is also important to note that multi-storey designs involve certain features, which are not required in two-storey dwellings – such as additional safety, waste disposal, and lift requirements. Table 2.1 given below shows the summary of typical relative proportions of costs of houses and apartments broken down into four basic elements.

TABLE 2.1: Relative proportions of costs of houses and apartments

Component	**2-storey house (Per cent)**	**3-storey apartment (Per cent)**	**8-storey apartment (Per cent)**
Substructure	11.2	6.7	9.0
Superstructure	52.4	44.6	55.2
Internal Finishing	18.9	25.5	13.4
Fittings & Services	17.5	23.2	22.4
Total	**100**	**100**	**100**

Source: Seeley (1996)

Various elements of alternative design solutions involving variations in the number of storeys have cost implications. The following examples were provided by Seeley (1996);

1. Comparison of alternative proposals to provide a prescribed floor area of office space in a rectangular shaped three-storey block or a six-storey L-shaped block. The six-storey block will involve increased costs in respect of the major elements for the reasons indicated below; while assuming that land is not a factor to be considered;

Foundations: more expensive foundations will probably be required in the six-storey block to take the increased load, although this will be partially off-set by the reduced quantity of foundations. The irregular shape will however increase the amount of foundations relative to floor area.

Structure: it is probable that a structural frame will be required in place of load-bearing walls with consequent higher costs, and there will be an additional upper floor and flight of stairs.

Cladding: the constructional costs will increase due to the greater amount of hoisting and the larger area resulting from the more irregular shape of the block.

Roof: constructional costs will be higher but these will be more than offset by the reduction in area of the roof.

Internal finishing: increased area due to more irregular shape and slightly higher hoisting costs will result in increased expenditure.

Plumbing, heating and ventilating installations: increased expenditure due to increased lengths of larger-sized pipework and ducting.

Passenger lifts: might not be provided with a three-storey block but will be essential for the six-storey.

2. Comparison of alternative proposals to provide a prescribed number of apartments of identical floor area and specification in two five-storey blocks and one ten-storey block is shown in Table 2.2 below.

TABLE 2.2: Comparison of Alternative proposals

Element	**Two five-storey blocks**	**One ten-storey block**
Foundations	Double the quantity of column bases and concrete oversite. Possibility of less costly strip foundations if load-bearing walls	Half the quantity of column bases but they will need to be larger and deeper. Possible need for more expensive piled foundations
Structural frame	Possibility of load-bearing walls. Otherwise two sets of frames but some smaller column sizes and less hoisting, so likely to be cheapest proposition	Larger column sizes to lower six-storeys as will carry heavier loads and increased hoisting will make this the more expensive arrangement.
Upper floors and staircases	One less upper floor and flight of stairs	One more upper floor and flight of stairs. Stairs may need to be wider to satisfy means of escape in case of fire requirements and there

		will also be increased hoisting costs.
Roof	Greater roof area	Reduced roof area but savings in cost partially offset by higher constructional costs.
Cladding	Less hoisting	May require stronger cladding to withstand increased wind pressures, and extra hoisting will be involved.
Windows	Slight advantage	Increased hoisting and possible need for thicker glass in windows on upper floors to withstand higher wind pressure.
External doors	Double the number of entrance doors	Might involve more doors to balconies
Internal partitions	Slight advantage	Some increased hoisting costs
Internal doors and joinery fittings	Much the same	Much the same
Wall, floor & ceiling finishes	Little difference	Little difference except for possibly slightly increased hoisting costs
External painting	Some advantage	Rather more expensive
Sanitary appliances	Much the same	Much the same
Soil and waste	Increased length of pipes	May need larger-sized pipes

pipes		on lower storeys
Cold and hot water services	Double the number of cold water storage tanks and may need two boilers	Larger cisterns, boilers, pumps, etc. and may need some larger pipes or cables and fittings
Heating and ventilating installations	Two separate installations but some savings due to smaller-sized pipes or cables	Cost advantage of single system but may be largely offset pipes or cables and fittings
Electrical installations	Two separate installations and intakes	Cost advantage of single system but probably more than offset by increased size of cables
Lifts	Two lift motor rooms but probably the same number of lift cars	Saving from one lift motor but may be necessary to install faster and more expensive lifts
Sprinkler installation	Two separate sprinkler systems	One system but some of pipework will need to be of larger size
Drainage	More extensive and expensive system	Some economies particularly in length of pipe runs and number of manholes
Siteworks	Likely to be more expensive in paths and roads but reduced ground area	Some savings likely
General services & Contingencies	May require two tower cranes if blocks are to be erected simultaneously	Taller tower crane needed

Source: Seeley (1996)

In a study of the association between building height and cost of commercial buildings, Tregenza (1972) found out that there is a statistically highly significant negative correlation between the percentage of `profitable' floor area and the number of storeys. The proportion of internal floor area not directly profitable like foyers, main corridors, lavatories, etc. approximately doubled between three storeys and fifteen. Tregenza's results also showed a statistically significant positive relationship between the net cost per square meter of `useful' space and the height of a building, with 66 percent rise between three storeys and eighteen. However, considerable diversity exists between the different buildings in the sample used: some have air conditioning and others have only minimum services; there is wide variation in the in the quantity of internal partitioning and in the unit costs of the cladding materials, internal finishes and fittings. These variances have effect on the reliability of the results.

Tan (1999) developed a simple analytic model to show how cost variation with building height is affected by technology, building design, demand and institutional factors. However, his model was too simple and does not capture certain institutional realities such as monopolistic pricing and zoning constraints. The model also relies on the unrealistic assumption that unit construction cost rises uniformly with height without capturing the dramatic changes in unit cost as some key thresholds (such as new foundation system or a different crane system) are reached. For the model to produce a more precise estimate, co-variances, about which only little is known, would be required.

2.3.5 Building envelope

The 'envelope' of a building is defined as the walls and roof, which encloses it. It forms the barrier between the inside of the building and the outside environments. It is a significant factor in the construction and running cost of a residential building and the greater the difference in these environments, the more expensive this envelope will be.

As stated earlier, the square shape is inherently economical in wall area, but the total envelope/floor area ratio will also depend upon the number of storeys that are chosen for the accommodation. For example, if the same floor area is arranged on two floors against single storey construction, the roof area is reduced more than the corresponding increase in wall area, so that the total envelope area would be reduced. The same thing might happen as the number of floors is increased to three while maintaining the same floor area, until the process eventually reverses when the increase in wall cost becomes greater than the roof saving. It is quite useful to know what the optimum number of floors to should be, as a design guideline.

Ferry and Brandon (1991) provide the formula below for determining the optimum number of floors for a square building;

$$N\sqrt{N} = \frac{x\sqrt{f}}{2h} \qquad (2.9)$$

Where N = optimum number of floors; x = roof unit cost divided by wall unit cost; f = total floor area in m^2; and h = storey height in m.

If the desired width in meters (w) is known, the formula for the rectangular building is:

$$N^2 = \frac{x*f}{2h*w} \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \qquad (2.10)$$

2.3.6 Circulation Space

Almost every type of building requires some circulation space to provide means of access between its constituent parts and in prestige buildings, spacious entrance halls and corridors add to the impressiveness and dignity of the buildings. However, an economic layout for a building will have as one of its main aims the reduction of circulation space to an acceptable minimum, having regard to the building type. Circulation space in entrance halls, passages, corridors, stairways and lift wells, can be regarded as ‘dead spaces’ which cannot be used for any profitable purpose and yet involves cost in heating, lighting, cleaning, decorating and in other ways.

One of the main aims of an economic layout will be reduce the amount of circulation space to an acceptable minimum. Reducing the width of the corridors for example, such that the people using the building suffer actual inconvenience cannot be justified. Corridors may also serve as an escape routes in case of fire. As with other parts of the buildings, cost is not the only criterion, which has to be examined – aesthetic and functional qualities are also very important. Circulation space requirements tend to rise with increases in the height of the buildings and it is accordingly well worthwhile to give special consideration to circulation aspects when designing high-rise buildings.

The proportion of floor space allocated to circulation purposes will vary between different types of building. The following circulation ratios (proportion of circulation space to gross floor area) will provide a useful guide:

Office blocks: 19%

Laboratories: 13%

Flats (four storey): 21% (Seeley, 1996)

These figures may seem high and their significance will be apparent when the published cost of a building calculated per square meter of gross floor area is converted to the cost of a square meter of usable floor space. For instance, an office block costing 1500 SR per m^2 of gross floor area with 20% circulation space is equivalent to 1800 SR per m^2 of usable area. This is particularly important in buildings, such as offices and apartments, which may be erected for letting where rent is usually calculated on usable floor area only.

2.3.7 Grouping of Buildings

The grouping and arrangement of buildings on a site can have significant influence on the total cost of the project. For example, inter-linking buildings often results in savings in costs, usually achieved by a reduction in the quantity of foundations, external walling, and other common elements of construction, and in using and maintaining the buildings (Ashworth, 1994). Sharing of common facilities is another advantage of grouped accommodation.

2.3.8 Mechanical and Electrical Services Elements

Buildings, especially commercial buildings are one of the biggest consumers of energy. In developed countries, buildings account for between 30% and 40% of the energy consumed (Carroll, 1982, and Kosonen and Shemeica, 1997). Mechanical and Electrical (M & E) services can account for up to 60% of the cost of a modern building (Turner, 1986). Aeroboe (1995) and Ellis (1996) indicate that air-conditioning is responsible for between 10% and 60% of the total building energy consumption, depending on the building type. Therefore, accurate early estimates of M & E services are very important. The services elements can also be estimated using the calculated areas of various components. By associating U-values (measure of thermal conductivity), and Y-values (measures of thermal inertia), with these components, the areas computed can be used in an energy program to compute the plant requirements and therefore costs. Since the calculation of energy usage and losses for design conditions have much in common, one model can be used for both functions.

Swaffield and Pasquire (1995) postulated that a cost modeling system, which considers the building function, level of services provision, and parameters, which describe the form of the building, would improve the accuracy of early cost advice of building services. In a later study, Swaffield and Pasquire (1999) verifies that the analysis of M & E services cost in terms of building form descriptors is valid, but that the commonly used gross floor area is not the most appropriate for M & E services cost estimates. They concluded that horizontal distribution volume and internal cube were the most significant variables for M & E services tender cost prediction.

Bojic *et al*. (2002) studied the thermal behavior of residential apartments for different characteristics of the apartment envelope and partitions. From their predicted results, it was found that providing insulation to external walls (except if originally thin) or increasing the thickness insulated external walls of residential buildings in hot climate region would not lead to significant cooling load reductions. However, it was observed that improving the thermal insulation of the partitions separating air-conditioned and non-air-conditioned spaces within the apartments was the most effective way of reducing cooling load.

2.3.9 Column Spacing

Single-storey framed structures almost invariably consist of a grid of columns supporting roof trusses and/or beams. By increasing the lengths or spans of roof trusses, the number of columns can be reduced and this may be of considerable advantage in the use of floor space below with less obstruction from columns. The trusses may need to be of heavier sections to cope with the greater loadings associated with larger spans, and will need to be of different design if the spans are lengthened sufficiently. In the like manner the sizes and weights of columns will need to be increased to take the heavier loads transmitted through the longer trusses, and this will partially offset the reduction in the number of columns. One method of assessing the probable cost effect of varying column spacing or span of trusses is to calculate the total weight of steelwork per square meter of floor space for the alternative designs, and the most economical arrangement will be readily apparent.

For instance, if steel columns 4.5m high were provided to support steel trusses 7.5m long at 4.5m centers, the weight of the columns would be approximately 7.7kg/m^2 of floor area. The weight of columns/m^2 of floor area would reduce to 5kg for trusses of 15m span and to 3.7kg for trusses of 24m span. On the other hand, with riveted steel angle trusses to 1/5 pitch and spaced at 4.5m centers, the weight of the trusses per square meter of the floor area would increase with lengthening of the roof spans as indicated below:

7.5m long trusses - 5.3kg/m^2

15m long trusses - 8.2kg/m^2

24m long trusses - 11.9kg/m^2

To the weight of columns and trusses must be added the weight of beams and purlins to arrive at the total weight of the steelwork (Seeley, 1996).

2.3.10 Floor Spans

Floor spans deserve attention as suspended floor costs increase considerably with larger spans. Further more, the most expensive parts of a building structure are the floors and roof, namely the members that have to thrust upwards in the opposite direction to gravitational forces. As a very rough guide, horizontal structural members such as floors cost about twice as much as vertical structural members like walls.

In the upper floors of blocks of flats, stiffness is an essential quality and meeting sound insulation requirements dictates a minimum floor thickness of 125mm. In this situation the most economical spans are likely to be in the order of 4.5 to 6.0m. With cross-wall construction floor spans are usually within the range of 3.6 to 5.2m. Two-way spanning of in-situ reinforced concrete floor slabs helps in keeping the slab thickness to a minimum, and one-way spanning is only economical for small spans (Seeley, 1996).

2.3.11 Floor Loadings

The Wilderness study (1964) has shown that variations in design of floor loadings can have an appreciable effect on structural costs. Adopting a 7.5m grid of columns and 3.0m-storey height, a comparison of structural costs for buildings with floor loadings of 2 to 10kN/m^2 respectively, shows an increase in cost of about twenty per cent for two-storey buildings to about forty per cent for eight-storey buildings for the higher floor loadings. Further increases of 2 to 4 per cent occur if the storey height is increase to 4.5m. Limited increases also arise from the wider spacing of columns when coupled with heavier floor loadings, and these increases become more pronounced in the taller blocks.

Heavy loads can be carried most economically by floors, which rest on the ground, rather than by suspended upper floors. Where heavy loads have to be carried by suspended floors it is desirable to confine them, wherever applicable, to parts of the building where the columns can be positioned on a small dimensional grid. As indicated previously, it is expensive to bridge large spans and it becomes quite a complex task to determine the point at which the unobstructed space stemming from larger spans equates the extra cost of providing it. Eccentric loading of vertical supports is always uneconomical and it may be worthwhile to increase a cantilever counterweight by moving the support nearer the centre of the load to reduce or eliminate the eccentricity. For this reason, perimeter supports are less economical than those provided by cross-walls.

2.3.12 Constructability

Sometimes called buildability, the term ‘constructability’ has been defined as the extent to which the design of a building facilitates the ease of construction, subject to the overall requirements for the completed building (CIRIA, 1983). The relative simplicity of constructing a building will obviously influence the cost of the project. Hence, a designer should have comparative ease of construction in mind at every stage of the design process, particularly in the early stages by taking a very practical approach. This necessitates a detailed knowledge of construction processes and techniques and the operational work on site, and is made much easier with the early appointment of the contractor.

The principal aim is to make construction as easy and simple as possible and to reduce waste, such as excessive cutting of components. Another aim is to make the maximum use of site plant and to increase productivity. Sometimes, a conflict may arise between ease of building and quality of construction and aesthetic requirements.

2.4 Computer Simulation

Computer simulation is defined as the process of designing a mathematical-logical model of a real world system and experimenting with the model on a computer (Pristker, 1986). A simulation model seeks to duplicate the behavior of the system under investigation by studying the interactions among its components. There are two basic categories of modeling a given problem: continuous and discrete-event. Differential equations are used to describe the progress of an activity in continuous modeling. However, discrete-event simulation views a model as a set of events and transitions.

Halpin (1977) popularized the application of simulation in construction with his development of a system called CYCLONE (CYCLic Operation Network). CYCLONE allowed the user to build models of construction operations using a set of abstract but simple constructs. Owing to the limited application of CYCLONE and its later derivatives especially in the industry, AbouRizk and Hajjar (1998) developed the special purpose simulation (SPS) because they found out that effective transfer of computer simulation knowledge to the construction industry will be best done through specialization and customization of the modeling, analysis, and reporting components of the simulation systems.

CHAPTER THREE

RESEARCH METHODOLOGY

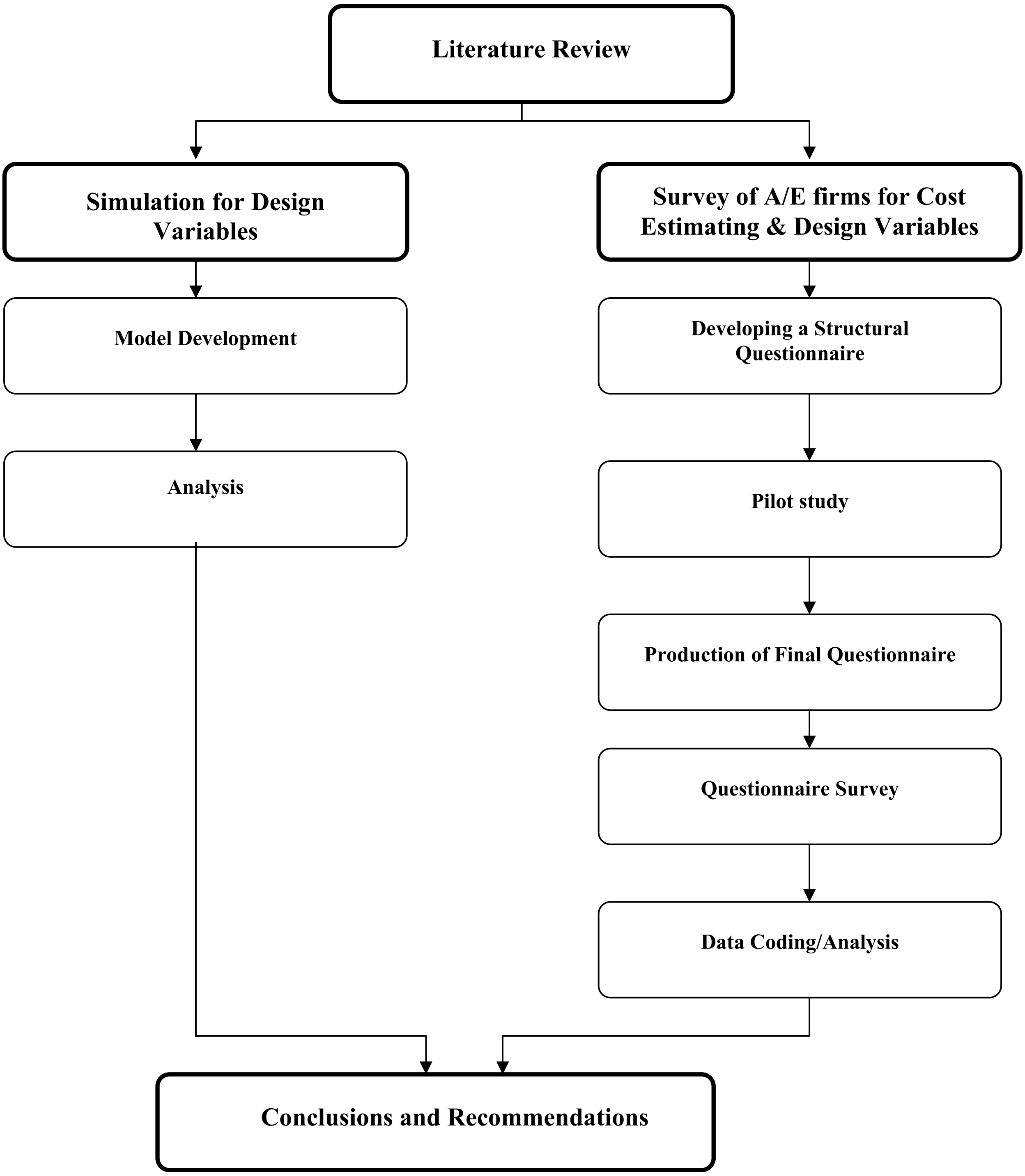
3.0 Introduction

This chapter presents all the necessary steps that were followed to achieve the research objectives set for this study, as stated in section 1.3. The research has been performed through three interdependent phases. These phases are Literature review, Survey of A/E firms, and Simulation. The phases and their steps are represented pictorially in the research design shown in Figure 3.1 and described in subsequent paragraphs.

3.1 Phase I: Literature Review

Extensive literature review (reported in Chapter Two) was carried out to acquire in-depth understanding of issues related to the subject matter. The established general rules-of-thumb on the effects of the design variables on cost were also reviewed. The discussions were partitioned into three parts. The first part briefly discussed the relationship between construction design and its cost. The second part discussed some of the methods of preparing construction estimates for residential buildings during the early stages of design development. The third part discussed some of the rules-of-thumb on the cost implications of design variables.

Figure 3.1: Research Design



The required information were collected from the following sources:

- Published international journals and conference proceedings related to Construction Engineering & Management, Construction Economics and Cost Engineering.
- Unpublished reports, projects, theses and dissertations related to Construction Engineering & Management, Construction Economics and Cost Engineering.
- Internet.

3.2 Phase II: Survey of A/E firms

The following information were required for investigating the procedures adopted by A/E firms in accounting for design variables during the early stages of a residential building project development:

1. The techniques used for determining the early cost estimates of residential buildings.
2. The factors influencing the choice of the technique and the evaluation of the A/E firms about the technique used.
3. The procedures adopted for accounting for design variables in the early cost estimates.

3.2.1 Required Data

The achievement of the objectives of this phase of the study necessitated the collection of various data. The following terms are being defined to provide a common understanding of their usage for the purpose of this study;

1. Cost estimation: technique followed by A/E firms in order to develop the probable cost of a project, from the available information. For the purpose of this study, cost estimation will refer to the techniques applicable to the forecasting or prediction of the cost of a residential building.
2. Pre-design estimating techniques: these are the methods of determining the probable cost of a building project at the early stages of the project, when designs are not yet developed.
3. Early cost estimate: any estimate that has been prepared from project inception up to and including funding approval.
4. Client: the owner who desires and initiates the construction of a residential facility either for occupation or for rental purpose.
5. The Designer/Design firm/Architectural-Engineering (A/E) firm: an organization or firm that provides design and consultancy services to the public, semi-public and private sectors in exchange for a fee. This may be done directly or by engaging the services of some other specialists in various aspects of the design and construction industry.
6. Design variable: a parameter of a building design that can be held constant in a particular case, but that can be varied in different other cases while providing

the same accommodation. For example, the building plan-shape, storey height, glazed area, etc.

7. Residential building: is a structure that is designed for the purpose of occupation as a shelter unit.
8. Villa: is a single family house that provide shelter, privacy, human need fulfillment, comfort (thermal, visual and spiritual), peace, affiliation and enjoyment to its residents.
9. Typical villa: a villa that is representative of a community in terms of facilities, components' types and sizes, building materials and construction system, that will not only meet but contribute to the formulation of the socio-cultural behavior of the community. For this study, the community is the Eastern Province of Saudi Arabia.
10. Perimeter to Floor ratio: is defined as the ratio of the area of external wall to that of the enclosed floor area.

3.2.2 Data Collection

This section of the study investigates the procedures adopted by Architectural/Engineering firms in accounting for design variables in the early cost estimates they prepare for residential buildings. The study is limited to the design variables that are Architectural in nature for a typical residential building design.

The principal research tool utilized for collecting the necessary ingredients is the questionnaire survey and the target respondents were Architectural/Engineering firms involved with design and consultancy work on residential buildings and practicing in the Eastern province of Saudi Arabia. The names and address of registered Architectural/ Engineering practicing in the Eastern province of Saudi Arabia were collected from the Chambers of Commerce and Industry for the Eastern province in Dammam. The list includes one hundred and forty (140) firms (see Appendix E).

Upon the development of the structural questionnaire, a pilot study was conducted on a random sample of 5 A/E firms. This pilot study served the following purposes:

1. Test the adequacy of the questions
2. Detect gray areas or ambiguous questions
3. Expand or compress the questions or choices, as may be required
4. Review the adequacy of the spaces allowed for each question
5. Estimate the average time required to fill out the questionnaire, and determine whether it is reasonable or not.

These firms were followed with several telephone calls and at the end of the week, four firms responded. The amendments that were considered to be necessary were effected and the final questionnaires were distributed by mail to all the 140 firms on October 7 2002. The reason for sending to all the firms is to ascertain conformity to criteria for inclusion in the study population, since the list available in the Chambers of Commerce did not classify the A/E's into specialties. Further investigation via telephone call to the firms revealed that only thirty (30) meets the study criteria of providing design and/or consultancy services to prospective clients of residential building facilities. These thirty (30) firms were therefore considered to be the study population.

Responses from the four firms that participated in and subsequently responded to the pilot study were received within a week. By January 7 2003, exactly two months after the main questionnaires were sent, only two further complete responses were received. Consequently, a reminder together with new set of the questionnaire was faxed to each of the twenty four (24) firms that were yet to respond. After several telephone contacts, three (3) further responses were received. A further twelve (12) questionnaires were sent on request on February 11 2003 and ten (10) responded. This brings the total completed responses received to nineteen (19), representing 63.3% response rate. Four (4) firms officially (in writing) declined participation as a result of perceived incompetence in responding to the research questions.

3.2.3 Population and Sample Size

Stemming from the scope of this research, the study population is defined to include all the A/E firms that provide design and/or consultancy services to prospective residential building owners, and practicing in the eastern province of Saudi Arabia. As stated earlier, only thirty firms conform to these criteria.

The size of the sample required from the population was determined based on statistical principles for this type of exploratory investigation to reflect a confidence level of 95%.. The sample size was determined using the following equations (Kish, 1995):

$$n_0 = \frac{(p * q)}{V^2} \tag{3.1}$$

$$n = \frac{n_0}{[1 + n_0/N)]} \tag{3.2}$$

Where n_0 = sample size from an infinite population.

p = the proportion of the characteristics being measured in the target population

q= complement of p, i.e. 1-p

V = the maximum standard error allowed

N = the population size

n = the sample size

To maximize the sample size n, the value of both p and q are each set at 0.5; the target population N is 30; and to account for more error in qualitative answers of this questionnaire, maximum standard error V is set at 10% or 0.1.

Substituting the values into equations 3.1 and 3.2 above, the minimum required sample is calculated to be 13.64. This means that the minimum sample required is

14 from the population. Therefore, the nineteen responses received can be regarded as being very good and highly representative of the population since the maximum standard error has been reduced to 7%.

3.2.3.1 Questionnaire Design

The questionnaire survey (provided in Appendix A) was utilized to investigate the methods used by A/E firms in determining the cost estimates of a proposed residential building during the early stages of the project. It also revealed the procedures adopted for accounting for the cost implications of design variables. The questionnaire comprised of a total of 48 (forty eight) questions spread across two sections.

The first part contains twenty one questions related to some general information about the respondent and the A/E firm. It also included questions on the demographics of the A/E firms. To ensure unbiased responses, completion of personal data was made optional. The second section addresses Study Objectives #1 and #2. This section contains twenty seven questions related to the estimating techniques utilized and factors influencing the choice of technique, the evaluation of the techniques utilized by the firms, factors influencing choice of the design variables, procedures for accounting for them in early cost estimates, the consequences of mal-assessment, and opinion on the importance of a systematic procedure for accounting for the design variables during the preparation of early cost estimates for residential buildings.

3.2.4 Data Analysis

The responses that were received from the survey participants were tabulated and analyzed individually. Simple mathematical techniques such as percentage and average were used in analyzing the data. However, in addition to these techniques, importance, reliability and severity indices were calculated as the case maybe, where necessary, to reflect the relative importance or reliability or severity of some of the relevant criteria over others. The indices were calculated as follows (Bubshait and Al-Musaid 1992):

$$\text{Index} = \left(\frac{\sum_{i=1}^{5} a_i x_i}{5 \sum_{i=1}^{5} x_i} \right) (100\%) \quad .. \quad .. \quad .. \quad .. \qquad (3.3)$$

Where a_i = constant expressing the weight given to i;

x_i = variable expressing the frequency of the response for; i = 1,2,3,4,5 and illustrated as follows:

x_1 = frequency of the "not important/reliable/severe" response and corresponding to $a_1 = 1$;

x_2 = frequency of the "somewhat important/reliable/severe" response and corresponding to $a_2 = 2$;

x_3 = frequency of the "important/reliable/severe" response and corresponding to $a_3 = 3$;

x_4 = frequency of the "very important/reliable/severe" response and corresponding to $a_4 = 4$;

x_5 = frequency of the "extremely important/reliable/severe" response and corresponding to $a_5 = 5$;

The average index for each major criterion is the average of all the indices of the individual criteria within the category.

The importance/reliability/severity indices were grouped to reflect the respondents' ratings as follows:

Extremely important/reliable/severe: $80 < I \leq 100$

Very important/reliable/severe: $60 < I \leq 80$

Important/reliable/severe: $40 < I \leq 60$

Somewhat important/reliable/severe: $20 < I \leq 40$

Not important/reliable/severe: $0 < I \leq 20$

3.3 Phase III: Simulation for Design Variables

This phase concerns the study of the effect of design variables on the cost of a residential building, in a series of spreadsheet simulation study. The study was limited to design variables that are architectural in nature. The effects of the other factors on construction cost were held constant during the simulation runs. The conclusions to a number of hypotheses formulated, among other things, were sought from the results of the simulation runs.

The following terms are being defined to provide a common understanding of their usage for the purpose of this study;

1. Design variable: a parameter of a building design that can be held constant in a particular case, but that can be varied in different cases while providing the same accommodation. For example, the building plan-shape, storey height, glazed area, etc.
2. Residential building: is a structure that is designed for the purpose of occupation as a shelter unit.
3. Villa: is a single family house that provide shelter, privacy, human need fulfillment, comfort (thermal, visual and spiritual), peace, affiliation and enjoyment to its residents.
4. Typical villa: a villa that is representative of a community in terms of facilities, components' types and sizes, building materials and construction system, that will not only meet but contribute to the formulation of the social-cultural behavior of the community. For this study, the community is the Eastern Province of Saudi Arabia.
5. Unit construction cost: is defined in terms of construction cost per unit square meter of Gross Floor Area.
6. Plan shape complexity: is defined in terms of irregularity of the plan layout. That is, a building with an irregular layout is said to have a complex shape while the building with a regular layout can be said to have a simple shape.
7. Perimeter to Floor ratio: is defined as the ratio of the area of external wall to that of the enclosed floor area.

8. Ceiling height: is the height measured from the top of the structural floor to the underside of the next structural floor/roof deck.

9. Total height: is the sum of all ceiling heights.

10. Cost Analysis: the systematic breakdown of cost data, generally on the basis of an agreed elemental structure, to assist in the preparation of cost plans for future schemes.

11. Element: one of a number of parts of a building which always perform the same function irrespective of their location or specification. For example, the substructure transmits the building load to the subsoil; a roof encloses the top of a building and provides protection from weather; etc.

12. Element Unit Quantity: the total quantity of the element expressed in units appropriate to the element concerned.

13. Element unit rate: a rate which when multiplied by the element unit quantity will give the total cost of the element. It is the cost associated with the delivery of a unit of each of the building element and comprises of material, labor and equipment costs required to complete a unit of the prescribed element

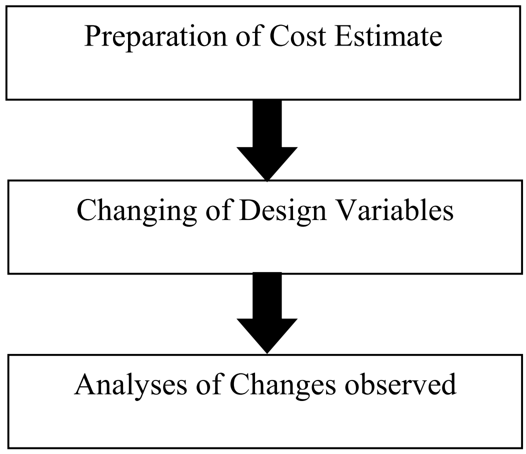
14. Element Cost: the total sum of money required to construct this part of a building.

15. Element Cost per Unit GFA: this is the element cost divided by the gross floor area. This provides the elemental cost contribution to the overall rate per square meter GFA for the project.

3.3.1 Model Development

The general framework model for this phase of the study is as represented in Figure 3.2 below.

Figure 3.2: Framework model



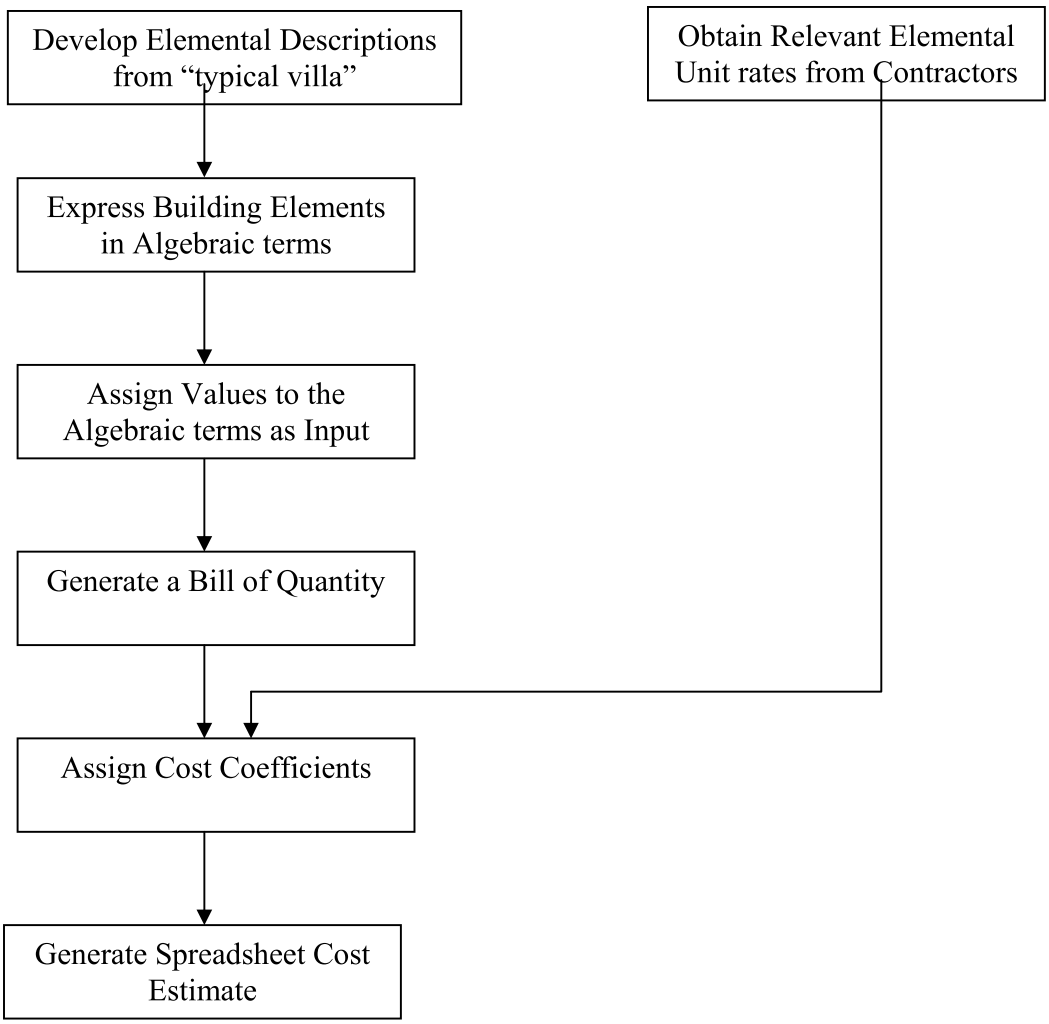
Details of the procedures adopted in preparing the cost estimates are described in the following sections.

3.3.1.1 Definition of Model Components and Model Building

Preparation of Cost Estimates

The procedure for the preparation of the cost estimates is as shown in Figure 3.3 below and described in details in the following paragraphs:

Figure 3.3: The Cost Estimate Model



Development of Elemental Descriptions

The data used for this aspect of the study was based on the major components of the 'typical villa' identified and defined by Shash and Al-Mullah (2002). That study was aimed at providing a base for the subsequent development of specialized construction cost and price indices in Saudi Arabia. These data were taken from a random sample of 200 building permits for residential villas issued in the different areas of the Dhahran

Municipality. Four categories of villas identified and the percentage of their frequency are:

1. Standard villa (65%)
2. Villa Luxe (25%)
3. Complex villas (7%)
4. Palaces (3%)

The sizes of the basic components of the developed 'typical villa' are given in Table 3.1 below. The items included in the analysis were those having high quantities and prices; and the criterion for inclusion in the definition of 'Typical Villa' was their frequencies of occurrence.

TABLE 3.1: Components of the 'Typical Villa'

S/No.	Components	Dimensions/specifications
1	Lot Area	$750m^2$
2	Ground Floor Area	$300m^2$
3	First Floor Area	$300m^2$
4	Extensions	Garage + Ground Floor + First Floor Extensions. $24m^2$ for each extensions
5	Foundation: Type Concrete Steel	 Separate Footing 3500psi Uncoated steel
6	Ground beams Size Concrete Steel	 20 x 50cm or 20 x 60cm 3500psi Uncoated steel
7	Flooring: Concrete Steel	 2500psi 20 x 20cm
8	Columns Size Concrete Steel	 20 x 50cm or 20 x 60cm 4000psi Uncoated steel

9	Slabs Type Concrete Steel	 Hordi slab (30cm thick) 3500psi Uncoated steel
10	Internal walls Type Size	 CHP Hollow masonry blocks 20 x 20 x 40cm
11	External walls Type Size	 Insulated masonry blocks 20cm
12	Internal Doors	Wooden Doors
13	External Doors	Steel Doors
14	Windows	Double Glass (6mm x 6mm x 6mm)
15	Wall Finish	Paint
16	Floor Finish	Screed and Marble
17	Ceiling Finish	Paint
18	External Finish	Paint
19	Air Conditioning System	Split Units
20	Electrical Loads	300 Amp with 3 panel boards

The model of the villa used for this study, shown in Appendix B, was developed under the following basic assumptions that:

1. The building design conforms to the requirements of dimensional coordination which encourages the use of standardized components' sizes for increased productivity.
2. The original layout of the building plan is a simple rectangular shape with external dimensions of 15m x 20m. The building is designed on two floors, each of 300m^2 and of 3m average storey height as provided by the 'typical villa'.
3. The same configurations in the base case can be achieved in from all the other layouts considered.

4. The effect of quality, indicated by the level of specification, has not been measured but it is been taken care of in the cost factor based on those prescribed in the "typical villa". Thus, specification is fixed.
5. Non-architectural components such as services, sitework and general items will all be given as percentages.

Elemental Unit Rates

Different elements of a building are best described by different units of measurement. The commonly used units with regards to residential building include linear meter, m; square meter, m^2; cubic meter, m^3; and number, nr for enumerated items. The cost associated with the delivery of a unit of each of the building element, known as the Element Unit Rate, comprises of material, labor and equipment costs required to complete a unit of the prescribed element. The rates used for the cost estimate are the averages of the prevailing rates obtained from seven contractors working for various pubic, semi-public and private residential clients in the Eastern province of Saudi Arabia. All the prices are in Saudi Riyals (3.75 Saudi Riyals = 1 US Dollar).

Expressing Elements in Algebraic Terms

This procedure of expressing building elements in algebraic terms is in effect a refinement of the traditional taking-off technique. It should be noted that although reliable, this procedure exhibits simplicity as wall thickness are ignored so as to facilitate the computerization of the estimate.

The algebraic forms of the key architectural components are presented under major headings below:

1. Substructure:

   a. Bulk excavation: = l x w x d where l = length of the building, w = width of the building and d = depth of excavation.

   b. Volume of excess earth disposed: = isolated footing + grade beams (described below).

   c. Backfill: = Bulk excavation – Volume of earth disposed.

   d. Isolated footing: suppose the average bay length = B_l and average bay width = B_w, the Volume of Isolated footing = $\left(\frac{l}{B_l}+1\right)x\left(\frac{w}{B_w}+1\right)$ x V_f where V_f = volume of one Isolated footing and with the values of $\left(\frac{l}{B_l}\right),\left(\frac{w}{B_w}\right)$ rounded up to the next whole integer number of bays.

   e. Grade Beams: This component forms a network connecting all the Isolated footings and is thus: $\left(wx\frac{l}{B_l}+1\right)+\left(lx\frac{w}{B_w}+1\right)$ x CSA_{gb} where CSA_{gb} = Cross-sectional area of the grade beam, and with the values of $\left(\frac{l}{B_l}\right),\left(\frac{w}{B_w}\right)$ rounded up to the next whole integer number.

   f. Ground floor slab: is simply l x w x t_1 where t_1 = thickness of the slab.

2. Shell

   a. Hordi slab: is also = l x w

b. Roof deck: is also = l x w x t_3 where t_3 = thickness of the slab. To cater for the perimeter treatments, an additional quantity 2 x (l + w) is considered.

c. Exterior wall E_w: (2 x (l + w) x h) – (W_d + D_{ed}) where h = average storey height, W_d = exterior window area and D_{ed} = exterior door area. Both W_d and D_{ed} could be given as percentages of the total exterior wall area, thus given as discounting factors.

d. Parapet wall: = 2 x (l + w)

e. Exterior wall finishes E_w + 2[2 x (l + w)]

f. Columns: = $\left(\frac{l}{B_l}+1\right)x\left(\frac{w}{B_w}+1\right)$ x h x CSA_{cl} where CSA_{cl} = Cross-sectional area of the column, and with the values of $\left(\frac{l}{B_l}\right),\left(\frac{w}{B_w}\right)$ rounded up to the next whole integer number.

g. Beams: $\left(wx\frac{l}{B_l}+1\right)+\left(lx\frac{w}{B_w}+1\right)$ x N x CSA_{bm} where CSA_{bm} = Cross-sectional area of the beam, N = number of storeys and the values of $\left(\frac{l}{B_l}\right),\left(\frac{w}{B_w}\right)$ are both rounded up to the next whole integer number.

h. Exterior Windows (W_d) and Doors (D_{ed}): both given as percentages of the exterior wall.

i. Roof coverings such as waterproofing materials: = l x w and in order to cater for the perimeter treatments such as flashings, an additional quantity 2 x (l + w) is considered.

3. Interiors

a. Partitions: here an attempt will be made to establish a relationship between the interior and exterior walls of a building. To do this, it will first be assumed that a building is but a collection of space, zones, or bays, which have been wrapped up into a whole. Suppose that all the zones making the whole have length of B_l and width B_w.

The total perimeter of the building will be given by P= $\left(wx\frac{l}{B_l}+1\right)+\left(lx\frac{w}{B_w}+1\right)$ and the sum of room perimeters against internal walls $I_w = P - E_w - W_d - D_{id}$, where E_w = girth of exterior wall (on inside face) including across the exterior windows (W_d) and doors (D_{id}), and D_{id} = internal door area.

b. Interior Doors: number obtained as D_i (number of bays or zones) $=\frac{GFA}{B_l x B_w}$.

c. Stairs: = N x *f*, where N = number of storeys and *f* = length of a flight.

d. Interior finishes:

i. Wall finishes: $= E_w + 2I_w$

ii. Floor finishes = 2 x (l x w)

iii. Ceiling finishes = 2 x (l x w)

Preliminary project descriptions for the various elements are also given in Appendix B.

Assignment of Value to the Algebraic Terms

Numerical values were then given to the algebraic terms and this leads to the generation of Element Quantities, which is the amount or quantity of the elements required, in terms of the chosen unit of measurement. These Element Quantities were generated automatically using formulae and commands in the spreadsheet package (Microsoft Excel).

Generation of Bill of Quantity

This is a table showing the descriptions developed from the "typical villa" described in the earlier section and the Element Quantities. The organization (coding system) of the Bill of Quantity 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 follows the progress of construction, built using systematic numbering system for effective coding and communication, and contains additional levels of details compared to the MASTERFORMAT system.

Application of Cost Coefficients

This step involves the application of a spreadsheet command for the multiplication of the Element Quantities with the Element Unit Rates to obtain the Element Costs, which are the requirements, in monetary terms, needed to complete each building element.

Generation of the Cost Estimate

The base estimate was prepared in the Elemental Cost Estimate Summary format and is inclusive of the following major components:

1. Architectural
2. Services
3. General Requirements (reported by Seeley, 1996; Ferry and Brandon, 1991 to be about 5% of the construction cost for residential buildings).

However, the following components have been excluded from the Base cost estimate because they do not have direct bearing/impact on this study:

4. Mark-ups for:
    i. design allowances (contingencies)
    ii. overhead and profit
    iii. inflation allowances
5. Site work
6. Professionals' fees – design and consultancy
7. Land Cost

The structure of the cost estimate presented includes:

- General data about the relevant case under study
- the Uniformat II coding
- brief description of each item (in line with the provisions of the 'typical villa'),
- the quantity for each item
- the unit of measurement
- the appropriate unit rate, composite in most cases
- the cost of each item
- the cost per unit GFA (m^2), and
- the percentage of the total cost that each item represents.

The methodology involves the supply of appropriate input data, which the spreadsheet utilizes in accordance with the built-in algebraic equations for each element, and the cost estimate satisfying the given conditions is generated. The input data are basic data that a designer can easily generate at the early stage of design development and the cost estimates which forms a good basis for sensitivity analyses are generated as output. The input data includes the following:

- Length on plan
- Width on plan
- Depth of excavation
- Bay length
- Bay width
- Volume of one Isolated footing
- Cross-sectional area of Grade beam
- Thickness of ground slab
- Thickness of roof deck
- Exterior window area (% of exterior wall area)
- Exterior door area (% of exterior wall area)
- Average storey height
- Number of storeys
- Cross-sectional area of column
- Cross-sectional area of beams

  The other items shown in the Input section are self-generated. The summary of the elemental cost estimate for the base case (layout A) is given in Table 3.2.

3.3.2 Simulation and Analysis

The spreadsheet simulation was carried out using Microsoft Excel software package to prepare the cost estimate. The parameters (design variables) of the base cost estimate were changed and results subsequently discussed.

CHAPTER FOUR

DISCUSSIONS OF RESULTS

4.0 Introduction

This chapter presents the analyses of data obtained from the survey of A/E firms on early cost estimates and the procedures adopted in accounting for design variables. The chapter also presents the results of the empirical analysis of design variables.

4.1 A/E Firms' Consideration for Design Variables

This section presents the analysis and findings of the data which were collected through questionnaire survey. The order in which the analysis is arranged follows the arrangement of the administered questionnaire. The first section will discuss the results on general information about the respondents and their firms. The second section will discuss the results on early cost estimates and the procedures adopted in accounting for design variables in the early cost estimates prepared for residential buildings by the A/E firms. The data used for the analysis were the responses obtained from nineteen (19) A/E firms who participated in the survey.

4.1.1 Characteristics of Respondents and Their Firms

This section contains information on the status and working life of the respondent in the firm, the firm's age, size, experience, category, specialization, capacity, clients, method of securing commission, and usage of specialized packages for estimating purpose.

4.1.1.1 Status of respondent and working life in the Firm

The distribution of the status of the respondents in the various A/E firms is shown in Table 4.1.

TABLE 4.1: Status of Respondents in the A/E Firms

Position	Frequency	Percent	Cumulative frequency	Cumulative percent
Owner/Vice-President/General Manager	14	73.7	14	73.7
Manager (Engineering/Contracts)	3	15.8	17	89.5
Project Manager	1	5.3	18	94.8
Estimating Supervisor	1	5.3	19	100

All the respondents indicated that they had worked for their firms for between 9 and 34 years, with an average of 18 years. It can be seen from Table 4.1 that about 95% of the respondents are senior personnel of the firms. These shows that the respondents are very experienced. This experience was reflected in the level of completeness, consistency and precision of the information provided, which provides further validity for the survey results.

4.1.1.2 Experience of Firm in Construction business

The levels of experience among the participating A/E firms in construction business have been classified as follows:

Very long (more than 15 years)

Long (between 10 and 15 years)

Short (between 5 and 10 years)

Very short (less than 5 years)

The distributions are shown in Figure 4.1. It can be seen that almost 60% of the firms reported over 15 years of experience and almost 90% of the firms have over 10 years in construction business. It can also be observed that none of the participating firms have less than 5 years experience in construction business.

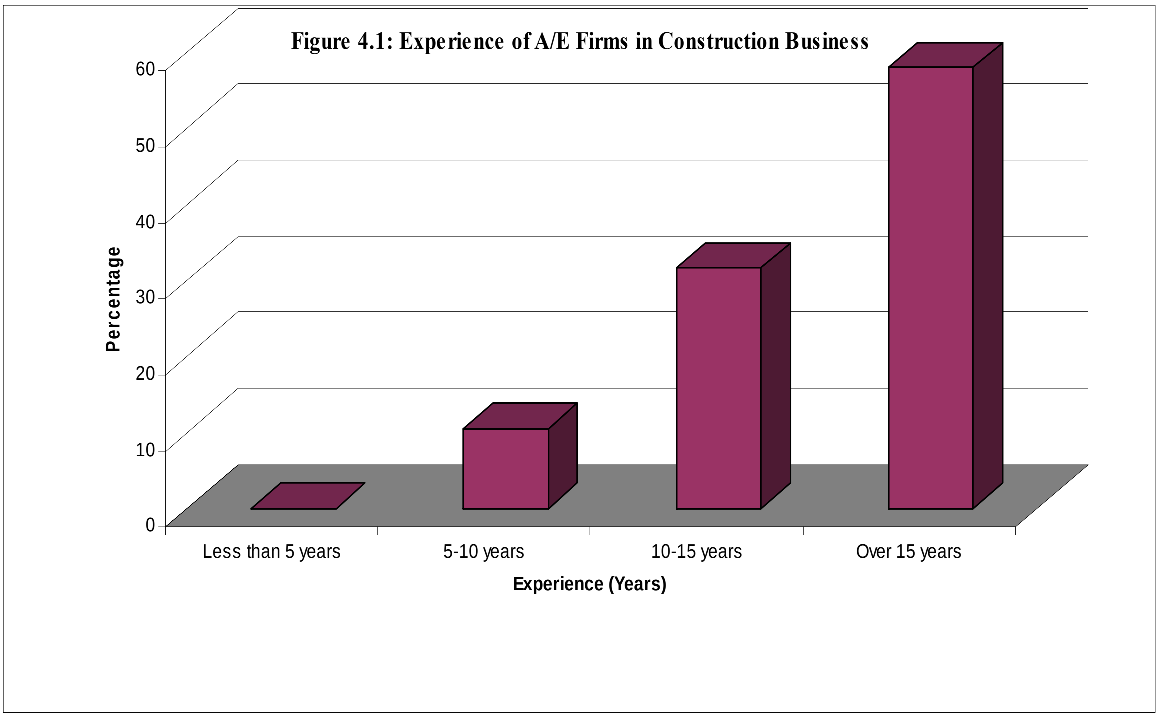


Figure 4.1: Experience of A/E Firms in Construction Business

4.1.1.3 Size of Firm

The sizes of the participating A/E firms have been classified in terms of number of employees as follows:

Very large (more than 150 employees)

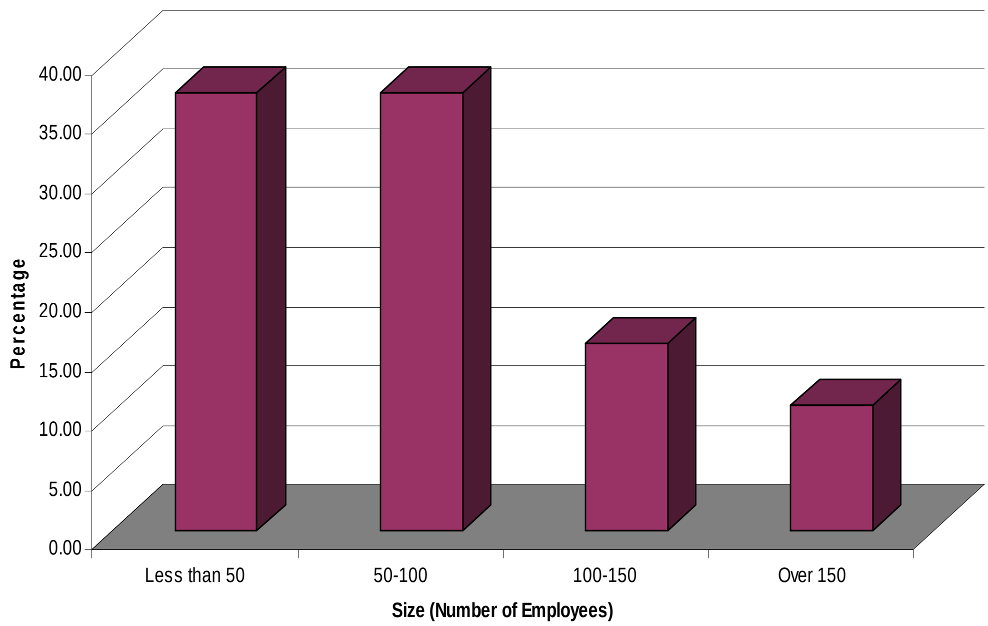
Large (between 100 and 150 employees)

Medium (between 50 and 100 employees)

Small (less than 50 employees)

The distributions of the company sizes are shown in Figure 4.2. It can be seen that only 2 firms (10%) have more than 150 employees while most of the firms (over 70%) have less than 100 employees. This distribution is not unexpected as the average size still far exceeds the global average size of A/E firms.

Figure 4.2: Sizes of Participating A/E Firms



4.1.1.4 Number of Employees working in the Estimating Unit of the Firm

The number of employees working in the estimating department of the participating A/E firms has been classified in terms of number as follows:

More than 15 employees

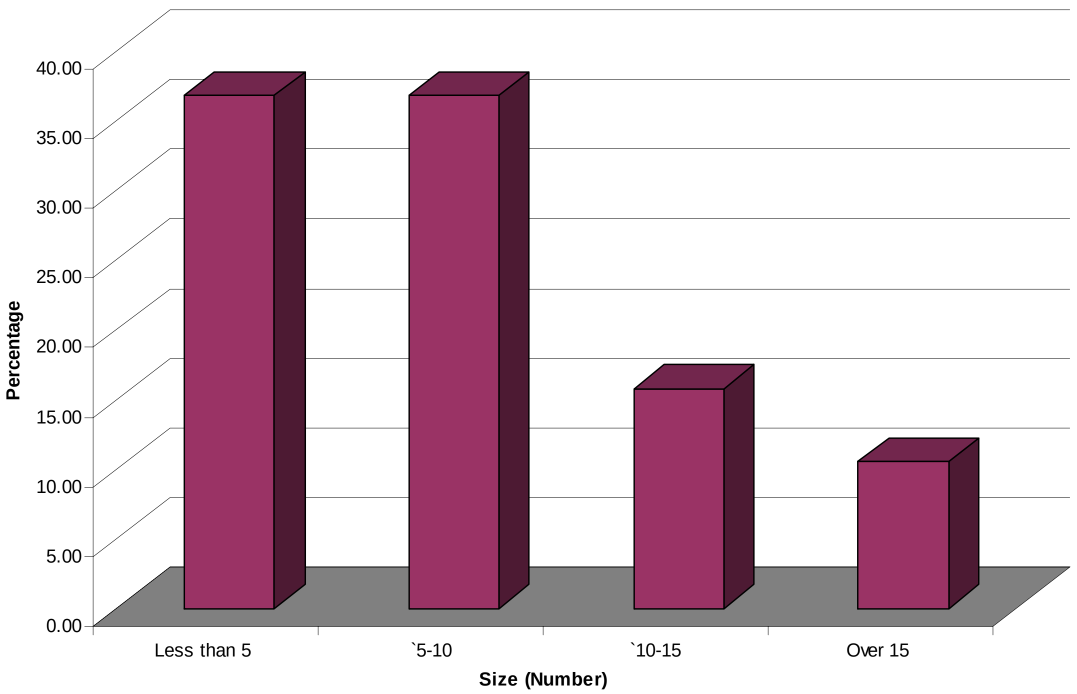
Between 10 and 15 employees

Between 5 and 10 employees

Less than 5 employees

The distributions of the company sizes are shown in Figure 4.3. It can be seen that only 2 firms (10%) have more than 15 estimating personnel while most of the firms (over 70%) have less than 10 employees working in the estimating units. The distribution bears correlation with the overall sizes of the firms on a ratio of 1:10.

Figure 4.3: Number of Employees working in the Estimating Unit



4.1.1.5 Average Years of Experience of Estimating workers as Cost Estimators

The levels of experience among the workers in the estimating units as cost estimators have been classified as follows:

Very long (more than 15 years)

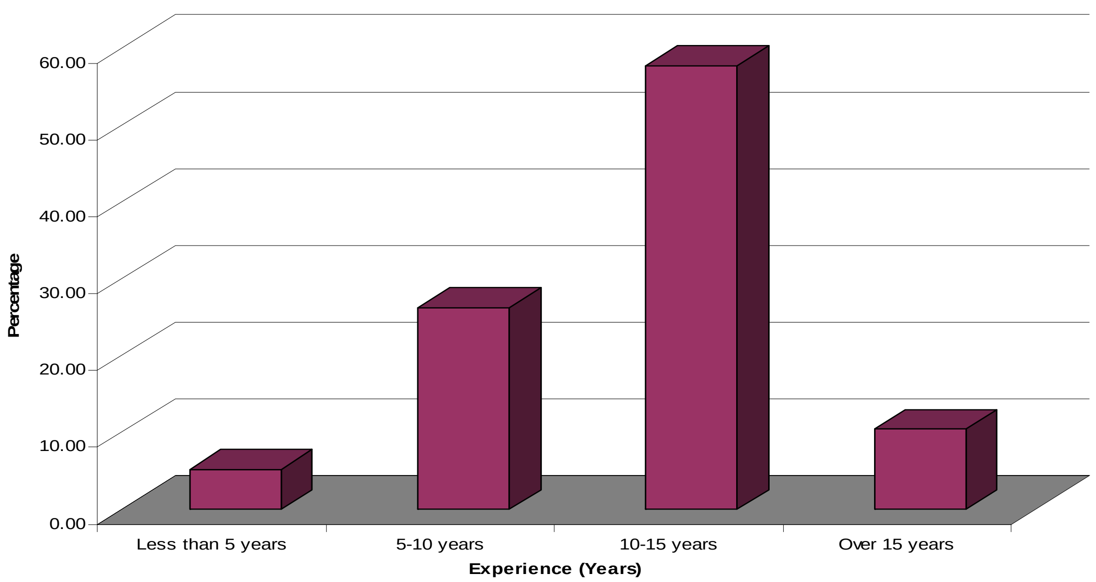
Long (between 10 and 15 years)

Short (between 5 and 10 years)

Very short (less than 5 years)

The objective of this and the previous sections is to ascertain the (un)availability of qualified personnel performing estimating functions in the various firms. It can be seen from the distributions shown in Figure 4.4 that it is only in one firm that the average experience of the estimators is less than 5 years. This means that the estimators in most of the firms are experienced, with average of over 10years of estimating experience.

Figure 4.4: Average Experience of Estimators



4.1.1.6 Firms' Category

The various categories of the A/E firms identified and relevant to this study have been classified as follows:

Design only

Consultancy only

Design and Consultancy

Cost Estimating (Quantity Surveying) only

All the firms (100%) that participated in this survey reported that they undertake both Design and Consultancy services.

4.1.1.7 Type of construction projects firms work on

The major categories of the construction projects handled have been grouped to include Residential buildings; Commercial buildings, Industrial buildings, and Highway construction. Figure 4.5 shows the distribution of the number of firms with the relative proportions of each category. It can be seen that 8 firms indicated that residential buildings constitute less than 20% of the volume of work carried out. Similarly, 7 firms indicated that commercial buildings constitute less than 20% of the construction work carried out by the firms. None of the firms has highway construction constituting more than 20% of the volume of construction work undertaken. The significance of the results provided by this section is the fact that all the firms confirm that they undertake design and consultancy services in residential building with industrial buildings holding the lion share. The proportion of the project types handled by the firms is given in Figure 4.6.

Figure 4.5: Type of Projects Firm work on

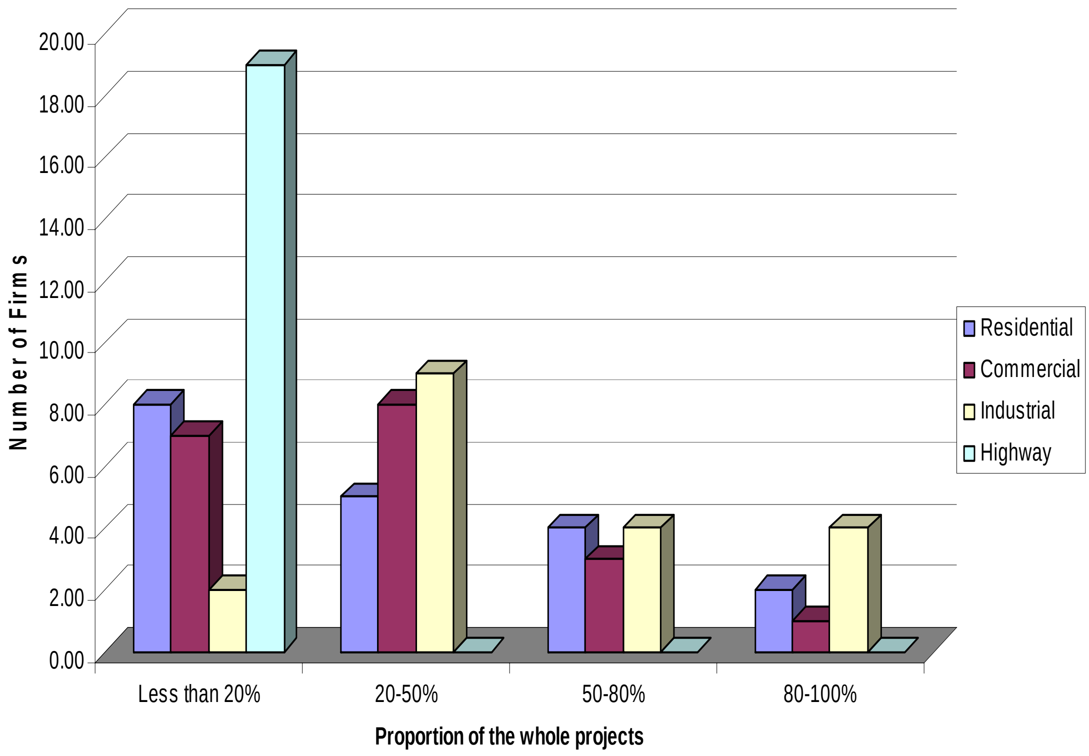
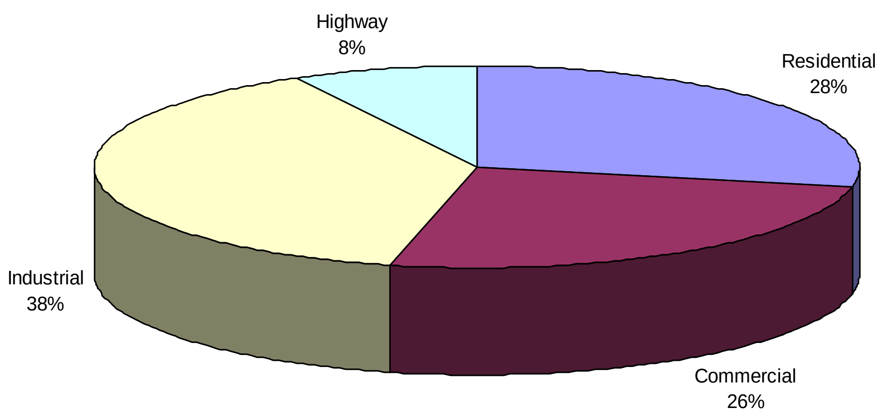


Figure 4.6: Distribution of Projects types handled by Firms



4.1.1.8 Average Size of Residential projects undertaken in last 5 years, in terms of Saudi riyals

The average size of residential building project handled by the participating A/E firms in the last 5 years has been classified in monetary terms as follows:

More than SR 20 million

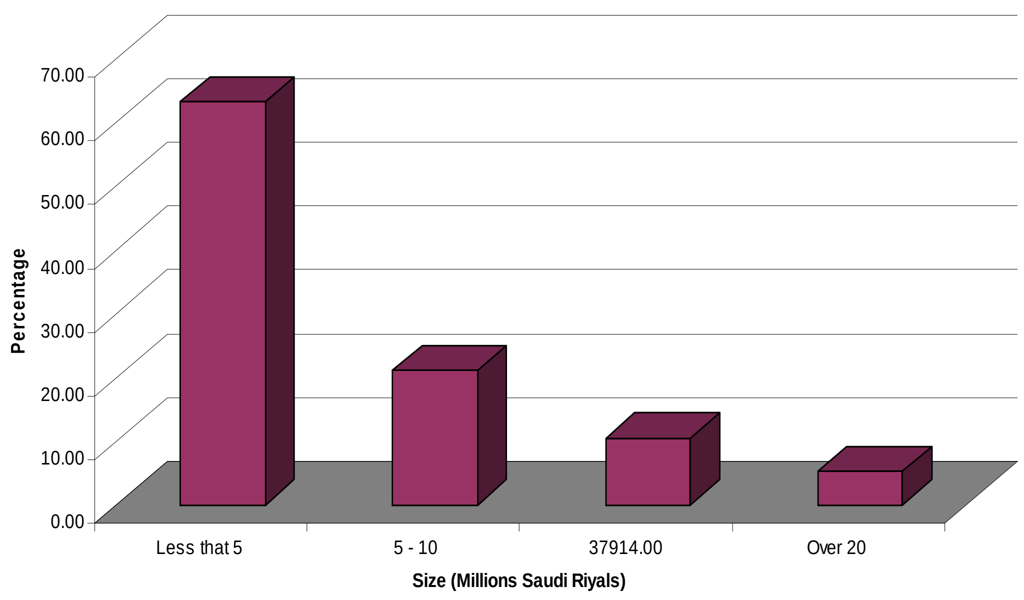
Between SR 10 and SR 20 million

Between SR 5 and SR 10 million

Less than SR 5 million

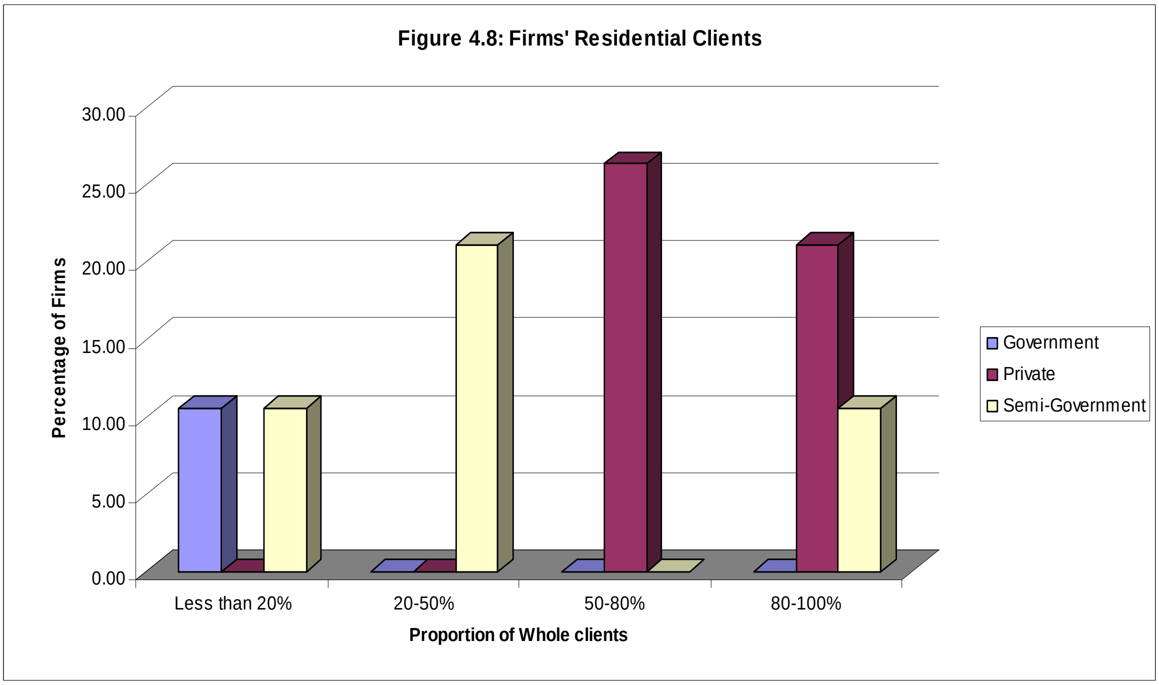
Although the classification was not explicit on whether it is in terms of value of a single unit or the overall value of the project, it can be seen that over 60% of the projects are of less than SR 5 million contract value. The distributions of the residential projects handled in the past 5 years by the participating firms are shown in Figure 4.7.

Figure 4.7: Average Size of Residential Project Undertaken in last 5 years



4.1.1.9 Firms' Residential Clients and Methodology of Engagement

The categories of residential clients identified include Government, Private, and Semi-Government sectors. Figure 4.8 shows that about 10% of the firms obtain less that 20% of residential projects from Government sources. It also shows that over 45% of the firms obtain over 50% of residential projects from the private sectors.

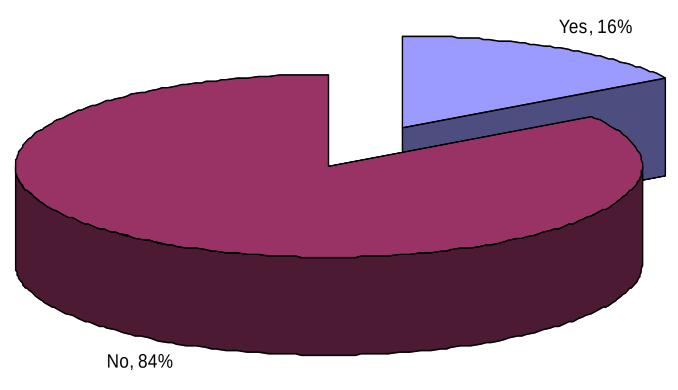


The survey results also showed that about 95% (18 firms) are engaged to perform cost consultancy jobs as part of the design package. Only one firm indicated that 30% of its cost consultancy job comes as part of the design package while the remaining 70% comes as a separate package.

4.1.1.10 Usage of Specialized Cost Estimating Software

Figure 4.9 shows that 84% of the firms do not use any specialized software to perform cost estimating services. This result is surprising, especially at this age of information technology. The software packages commonly used by the firms using specialized packages include Estimate I and Caesar I which are German-made software packages. The average length of usage was found to be 5 years and each of the three firms using specialized packages provided a level of satisfaction of 4 on a scale of 5, which gives a reliability index of 80. This indicates that the users have found the packages to be very reliable. It is however a common knowledge that most of the firms use generalized spreadsheet packages such as Microsoft Excel and Lotus for the preparation of cost estimates.

Figure 4.9: Usage of Specialized Cost Estimating Software



4.1.2 Early Cost Estimates and Design Variables

This section contains information on early cost estimates for residential buildings and the procedures adopted by the A/E firms in accounting for design variables in the early cost estimates they prepare for residential buildings.

4.1.2.1 Preparation of Early Cost Estimates and Estimating techniques

Although all the participating firms indicated that they perform cost consultancy services on residential buildings, survey shows that only 10 firms (53%) prepare early cost estimates. This means that the other 47% only perform cost consultancy at later stages of the project.

The summary of the estimating technique used for preparing early cost estimates is provided in Table 4.2.

TABLE 4.2: Summary of Estimating Techniques uses in preparing Early Cost Estimates

Technique	Frequency	Percent	Cumulative frequency	Cumulative percent
Prevailing Cost of Square Meter	3	30	3	30
Approximate Quantities Method	2	20	5	50
Database of similar projects	3	30	8	80
Unit rate (Time and Work)	2	20	10	100

Table 4.2 shows that the most commonly used estimating techniques are the prevailing square meter and database of similar projects, both of which relies on the previously completed projects.

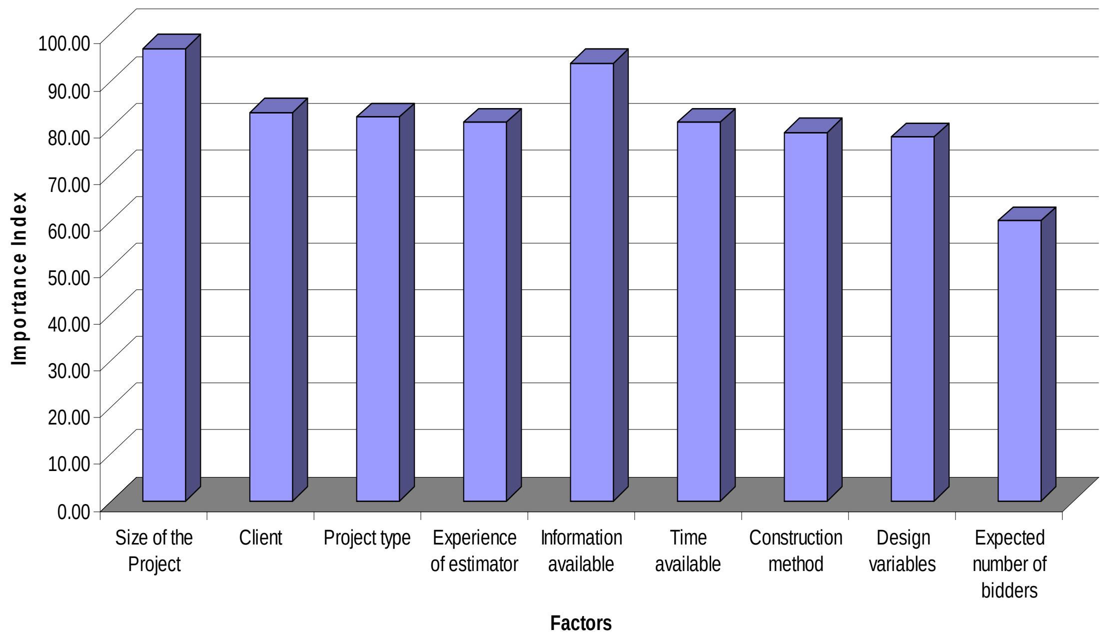
4.1.2.2 Factors that impact the decision for selecting estimating technique

The participating A/E firms were asked to assess the importance of many factors potentially affecting their decision in selecting early cost estimating technique, to which all the firms responded to. The importance indices were calculated to reflect the relative importance of the factors. Table 4.3 and Figure 4.10 show the importance indices and ranking of each of the factors.

TABLE 4.3: Factors that impact the decision for selecting estimating technique

Factors (1)	Extremely important (2)	Very important (3)	Important (4)	Somewhat Important (5)	Not important (6)	Importance Index (7)	Rank (8)
Size of the project	16	3	0	0	0	96.84	1
Client (owner)	9	4	6	0	0	83.16	3
Project type	9	3	7	0	0	82.11	4
Experience of estimator	6	8	5	0	0	81.05	6
Information available	13	6	0	0	0	93.68	2
Time available	8	4	7	0	0	81.05	5
Construction method	6	5	7	0	0	78.89	7
Design variables	8	1	10	0	0	77.89	8
Expected number of bidders	4	4	3	4	4	60.00	9

Figure 4.10: Ranking of Factors that impact decision for selecting estimating technique



Based on the classification defined earlier, Table 4.3 reveals that six factors are "extremely important" factors and the other three are "very important" factors in deciding the early cost estimating technique to be used for residential projects. It also shows that the most important factor in deciding the estimating technique to be used is the size of the project while the least important factor is the number of bidders. This distribution may be due to the estimating techniques that are in common use which tend to rely on data from previously completed similar projects. Thus, the reason why factors either directly related to the characteristics of the project or the owner have more impact on the choice of estimating technique. Three firms have also suggested that both Value Engineering and Constructability are extremely important factors.

4.1.2.3 Reliability of estimating technique utilized

The participating A/E firms were also asked to rate the reliability of the estimating technique they use in preparing early cost estimates for residential buildings. This rating was based on the comparison of the estimates prepared by the firms in previous projects with the tender prices for the same projects. The rating is transformed into reliability index and the results are given in Table 4.4

TABLE 4.4: Reliability of estimating technique

Factors (1)	Extremely reliable (2)	Very reliable (3)	Reliable (4)	Somewhat reliable (5)	Not reliable (6)	Reliability Index (7)
Reliability of estimating technique	5	5	9	0	0	75.76

The reliability level of the estimating technique used by the firms in preparing early cost estimates is "very reliable". While it was shown that the factors which reveal the project characteristics have the greatest impact on the choice of estimating technique, the highest reliability is not attained probably because design variables, which tremendously diagnoses project characteristics more than any factor, are not given adequate attention.

4.1.2.4 Factors that impact decision on design variables of residential building designs

The participating A/E firms were requested to indicate the impact level of the identified factors in decisions relating to each design variable. The importance indices were calculated to reflect the relative importance of the factors. Table 4.5 shows the importance indices and ranking of each of the factors.

TABLE 4.5: Factors that impact the decision on design variables

Factors (1)	Extremely important (2)	Very importa nt (3)	Important (4)	Somewhat important (5)	Not important (6)	Importance Index (7)	Rank (8)
Plan Shape							
Shape of the plot	5	10	1	3	0	77.89	1
Functional requirements	8	1	1	9	0	68.42	2
Intended use	6	2	4	7	0	67.37	3
Total number of storeys							
Cost of land	13	2	3	1	0	88.42	1
Prestige	4	5	4	6	0	67.37	3
Planning laws	10	1	2	5	1	74.74	2

Average storey height							
Intended use	11	2	2	4	0	81.05	1
Environmental considerations	6	1	9	3	0	70.53	2
Type of A/C system	4	2	7	6	2	60	3
Amount of circulation area							
Expected traffic	7	7	2	2	1	77.89	1
Safety	6	4	5	4	0	72.63	2
Building codes	4	8	4	2	1	72.63	3
Percentage of exterior wall area to be glazed							
Functional requirements	7	2	3	3	4	65.26	3
Building codes	1	11	5	1	1	70.53	2
Owner’s wish	14	1	3	1	0	89.47	1
Mechanical and Electrical (M & E) services							
Percentage of glazed wall area	5	6	5	3	0	73.68	1
Perimeter length	5	2	3	6	3	60	8
Total building height	5	2	5	7	0	65.26	4
Volume of plant rooms	5	3	4	5	2	64.21	5
Total enclosed volume	5	6	5	1	2	71.58	2
Total floor area	5	3	2	6	3	61.05	7
Building services codes	5	6	2	5	1	69.47	3
Intended use	3	4	5	7	0	63.16	6

Based on the classification defined earlier, Table 4.5 reveals that three factors are "extremely important" factors, and the other twenty factors are "very important" decision relating the aforementioned design variables. The factors rated to be extremely important happened to be those primarily controlled by the owners and outside the jurisdiction of the consultants. This indicates the strong influence that the owners have over decisions in respect of the design variables and a serious challenge to the designers who are required to offer professional advice to the owners.

4.1.2.5 Application of Constructability as a design tool

The participating A/E firms were asked to rate the importance of the application of constructability as a design tool and the rating was transformed into importance index and the result is given in Table 4.6

TABLE 4.6: Application of Constructability as a design tool

Factors (1)	Extremely important (2)	Very important (3)	Important (4)	Somewhat important (5)	Not important (6)	Importance Index (7)
Application of Constructability	13	6	0	0	0	93.68

The importance level for the application of constructability as a design tool is "extremely important". Constructability has obvious benefits, which includes ease of construction in order to minimize waste while maximizing use of site plants and thus productivity, hence the justification for level of importance. These benefits will have highest value if the constructability is applied in the early stages of the design development when the cost of effecting changes will be minimal.

4.1.2.6 Average Percentage for Circulation space, Glazed area and M & E services

The participating A/E firms were asked to indicate the average allowances they make in residential building designs for circulation space as a percentage of total floor area, glazed area as a percentage of total exterior wall area, and cost of M & E services as a percentage of total building cost. The minimum and maximum values and the standard deviation of the values provided by the firms are reported in Table 4.7.

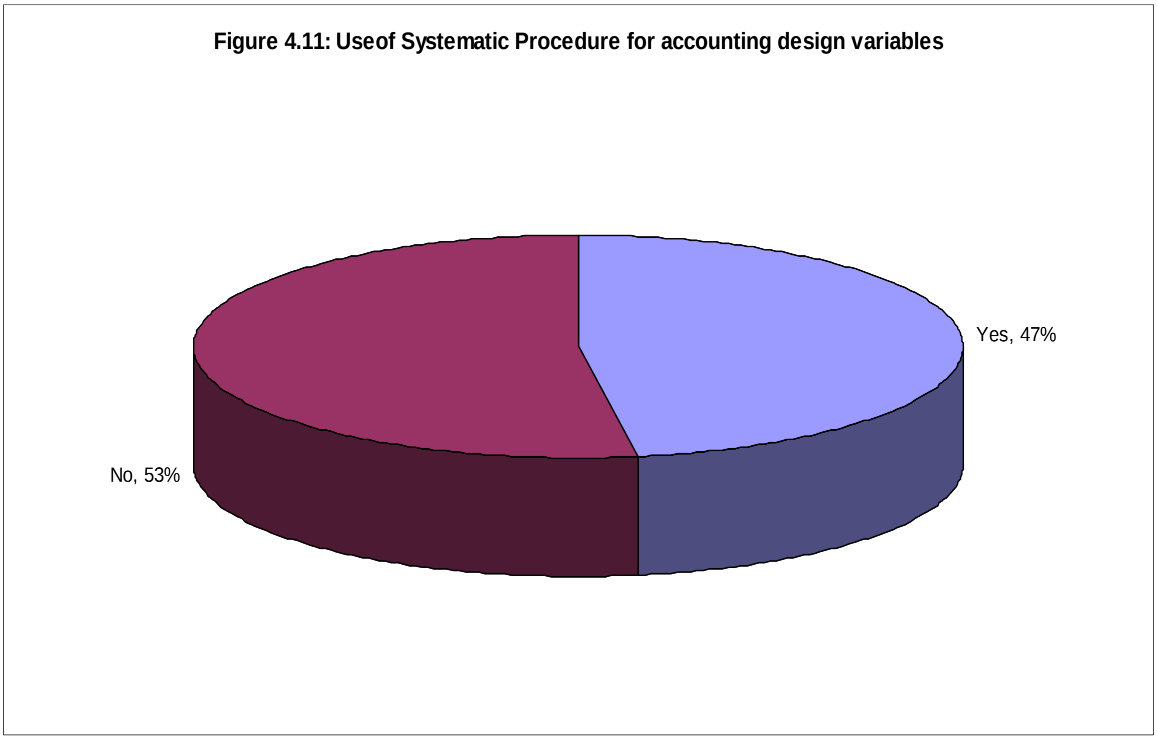
TABLE 4.7: Average Percentages for Circulation space, Glazed area, and M&E services

Variable (1)	Minimum (2)	Maximum (3)	Standard deviation (4)	Average (5)
Circulation space	12	60	15.76	31.68
Glazed area	15	70	15.12	29.21
M&E services cost	15	40	7.60	23.68

These results corroborate the previous findings of Ferry and Brandon (1991), Ashworth (1994), and Seeley (1996).

4.1.2.7 Use of Specific Systematic procedure for accounting for design variables

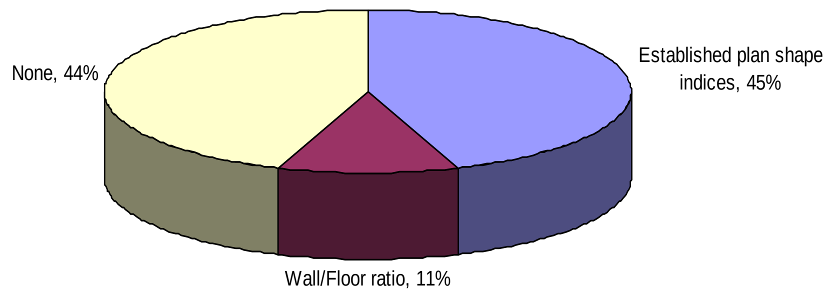
It can be seen from Figure 4.11 that only 47% of the participating A/E firms indicated that they use systematic procedures in accounting for design variables in the early cost estimates they prepare for residential buildings. The procedures adopted for each design variable will be explored in the following sections.



4.1.2.8 Procedure for accounting for Plan Shape

It can be seen from Figure 4.12 that only 1 firm reported the use of Wall to Floor ratio in accounting for plan shape while 45% (4 firms) reported the use of other plan shape indices, without providing any details as to which indices are been used. The other 44% of the firms indicated that they use neither the existing plan shape indices nor Wall to Floor ratio, and none of them provided any explanations of the methodology followed in accounting for plan shapes in their early cost estimates.

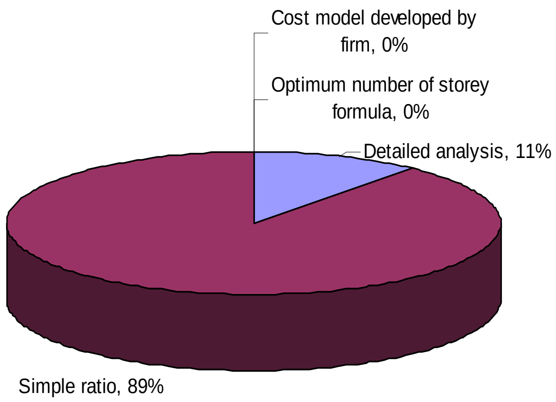
Figure 4.12: Procedures for Accounting for Plan Shape



4.1.2.9 Procedure for accounting for Number of storeys

It can be seen from Figure 4.13 that 11% of the participating firms reported the use of detailed analysis to account for changes in number of storey for a residential building. Detailed analysis could be cumbersome and time-consuming and may lead to inadequate exploration of all the options that may be available to be able to choose an optimum number of floors. Research findings have developed formulae for determining optimum number of floors that will provide the most economical design. The other 89% reported the use of simple ratio for adjusting for changes in the number of floors. Although, this may provide a fairly reasonable idea for storeys ranging from one to three, the scenario may drastically change thereafter due to changes in the form of foundation, structural framework, roof, etc. Thus, the application of simple ratio would provide inaccurate assessment of the plan shape variations.

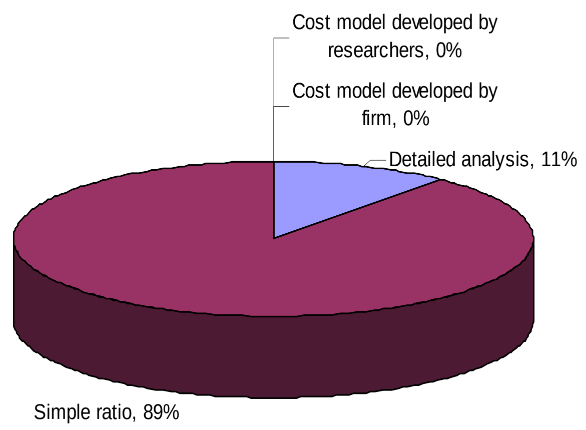
Figure 4.13: Procedure used for accounting Number of storeys



4.1.2.10 Procedure for accounting for Average storey height

It can be seen from Figure 4.14 that 11% of the participating firms reported the use of detailed analysis while 89% reported the use of simple ratio to account for changes in the average storey height in early cost estimates of residential buildings. The use of simple ratio by the majority of the firms can give misleading results because the costs of non-vertical components such as floors and roof, which could constitute significant proportion of the total cost, do not rise proportionately with the height. Some of the models developed by researchers have taken these into account.

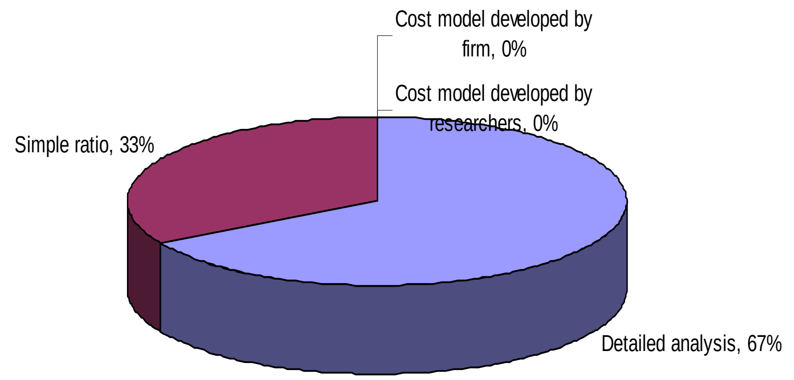
Figure 4.14: Procedures used for accounting Average storey height



4.1.2.11 Procedure for accounting for Circulation space

The result shown in Figure 4.15 indicates that 67% of the participating firms reported the use of detailed analysis while 33% reported the use of simple ratio to account for circulation space in early cost estimates of residential buildings. Adjustments of circulation space are particularly useful when analyzing the relationship between the gross floor area and the net usable area for commercial apartments for the purpose of determining profitability. The need for a systematic procedure in accounting for this variable cannot be over-emphasized because its requirements changes with provisions of building codes to fulfill the requirements of the other variables such as safety needs and lift/staircase arising from increase in number of storeys.

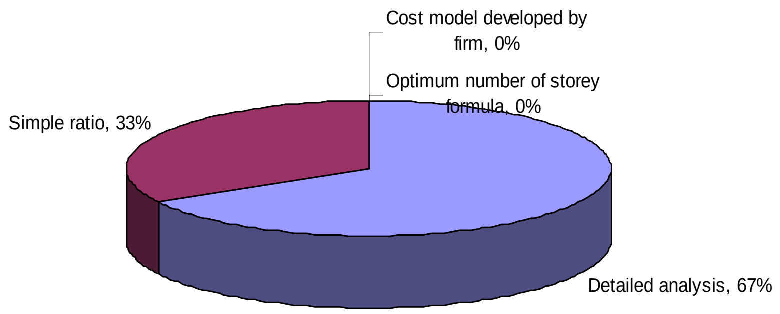
Figure 4.15: Procedure used for accounting Circulation space



4.1.2.12 Procedure for accounting for Glazed area

It can be seen from Figure 4.16 that 67% of the participating firms reported the use of detailed analysis while the remaining 33% reported the use of simple ratio to account for glazed area in early cost estimates of residential buildings. Glazed wall area constitutes an important variable as clients often seek adjustments to this component, as expressed by the rating of factors impacting glazed area in section 4.1.2.4. The relationship between wall area and specifically, the proportion of glazed area therefore becomes important to effectively deal with necessary adjustments.

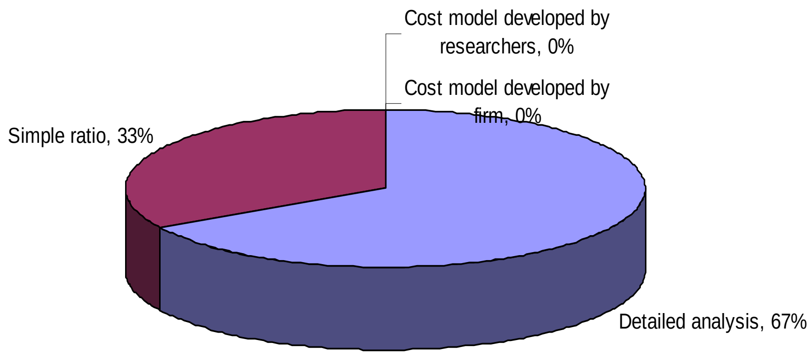
Figure 4.16: Procedure used for accounting Glazed area



4.1.2.13 Procedure for accounting for M & E services

The result shown in Figure 4.17 indicates that 67% of the participating firms reported the use of detailed analysis while 33% reported the use of simple ratio to account for M & E services. With M&E services constituting almost 25% of the total cost of a residential building as indicated by the respondents in section 4.1.2.6, a systematic procedure becomes important especially that other variables that are dictated by the owner's wish such as glazed area greatly affect decisions on the M&E services in residential building designs.

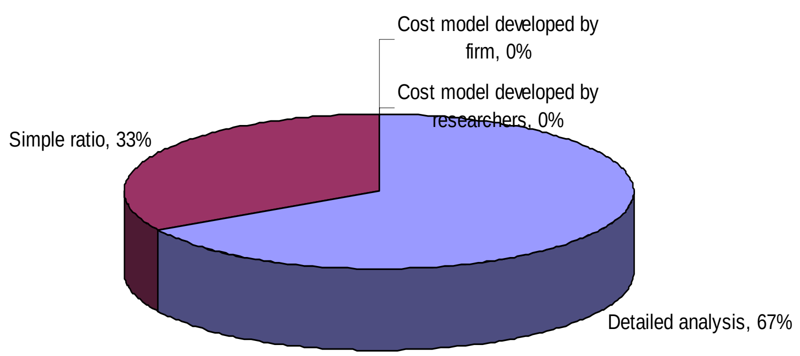
Figure 4.17: Procedure used for accounting M & E services cost



4.1.2.14 Procedure for accounting for Density of internal partition

It can be seen from Figure 4.18 that 67% of the participating firms reported the use of detailed analysis while the remaining 33% reported the use of simple ratio to account for internal divisions that may be required in a residential design.

Figure 4.18: Procedure used for accounting Density of internal partition



4.1.2.15 Consequences of mal-assessing cost implications of design variables in early cost estimates

The participating A/E firms were requested to indicate the level of severity of the consequences of both under-assessment and over-assessment of the cost implications of design variables in the early cost estimates prepared for residential buildings. The severity indices were calculated to reflect the relative impact of the outcomes. Table 4.8 shows the importance indices and ranking of each of the factors.

TABLE 4.8: Consequences of mal-assessing cost implications of design variables

Outcome (1)	Extremely severe (2)	Very severe (3)	Severe (4)	Somewhat severe (5)	Not severe (6)	Severity Index (7)	Rank (8)
Under-assessment 70.00[a]							
Recommendation of infeasible project	4	6	5	4	0	70.53	2
Project abandonment	2	8	2	7	0	65.26	4
Disappointing expected returns	6	7	2	4	0	75.79	1
Sub-standard quality work	4	5	5	5	0	68.42	3
Over-assessment 75.79[b]							
Loss of owner's confidence on A/E	11	3	2	3	0	83.16	1
Rejection of feasible project	6	4	6	3	0	73.68	2
Lost opportunities	6	3	6	3	1	70.53	3

Based on the classification defined earlier, Table 4.8 reveals that one factor is "extremely severe" while the other six factors are "very severe" consequences of mal-assessing the cost implications of design variables. The Table also shows that disappointing returns and loss of owner's confidence in the designer as the most severe consequences of under-assessing and over-assessing the cost implications of design variables in early cost estimates respectively. Project abandonment and lost future opportunities were also shown to be the least severe consequences of under-assessment and over-assessment respectively. It can also be seen from the average severity indices that the consequences of over-assessment is greater than that of under- assessment. The rankings are represented diagrammatically in Figures 4.19 and 4.20.

Figure 4.19: Ranking of Consequences of under-assessing cost implications of design variables

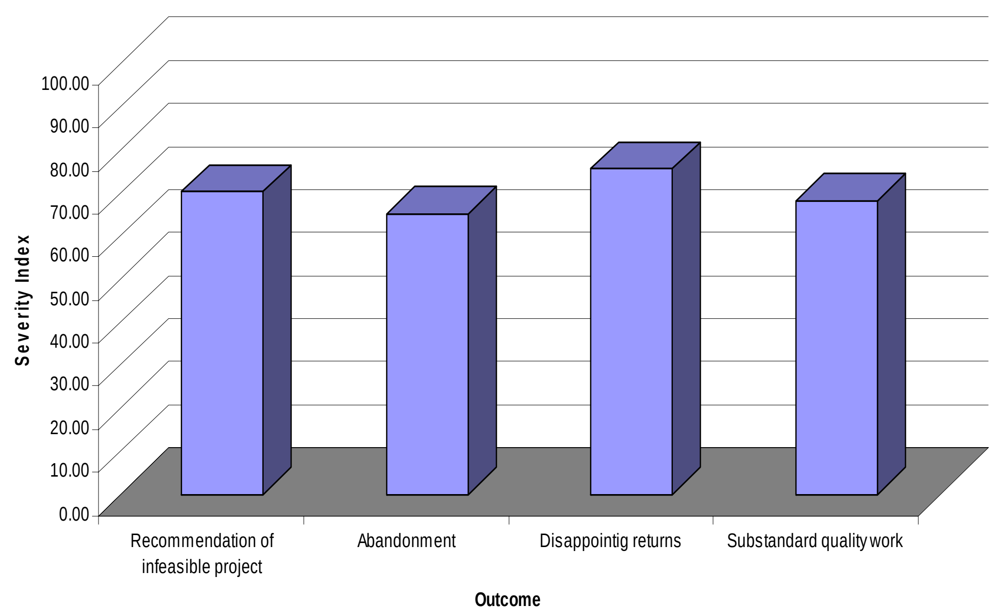
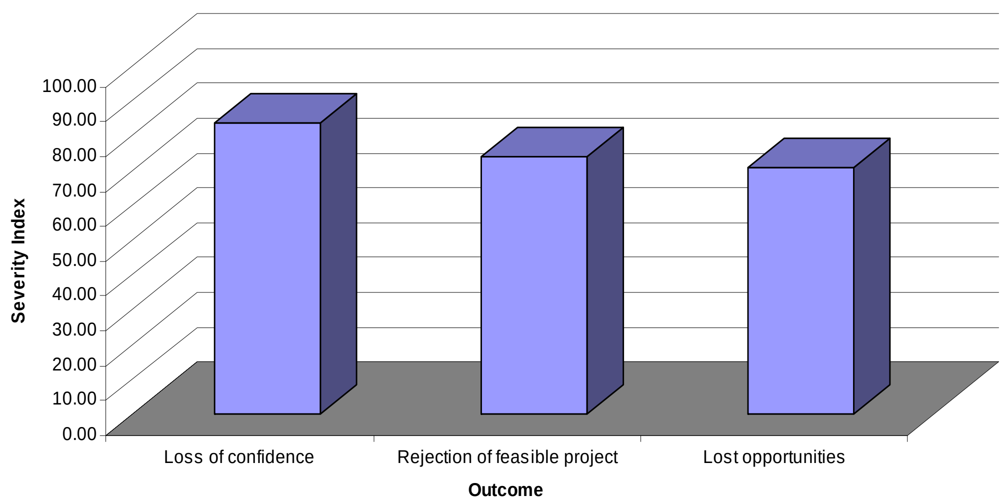


Figure 4.20: Ranking of Consequences of over-assessing cost implications of design variables



4.1.2.16 Importance of applying systematic procedures for assessing design variables

The participating A/E firms were asked to rate the importance of the application of systematic procedures in accounting for design variables in early cost estimates. The benefits to be derived from such application of systematic procedures include ease of adjustments, feasibility studies, evaluation of alternative options and reliability of estimating technique. The rating is transformed into importance index and the result is given in Table 4.9

TABLE 4.9: Importance of applying systematic procedures for assessing design variables

Factors (1)	Extremely important (2)	Very important (3)	Important (4)	Somewhat important (5)	Not important (6)	Importance Index (7)
Importance of applying systematic procedures	5	14	0	0	0	85.26

The importance level for the application of systematic procedures for accounting for design variables is “extremely important”. This shows that the firms have realized the strategic importance of developing or adopting systematic procedures for assessing design variables in order to carry out effective cost consultancy services for the clients.

4.1.2.17 Reliability of procedures for accounting for design variables

The rating of the reliability of procedures adopted by the participating A/E firms in accounting for design variables in early cost estimates are transformed into reliability indices and shown in Table 4.10.

Factors (1)	Extremely reliable (2)	Very reliable (3)	Reliable (4)	Somewhat reliable (5)	Not reliable (6)	Reliability Index (7)
Reliability of procedures for accounting design variables	3	3	12	1	0	68.42

TABLE 4.10: Reliability of procedures adopted for accounting for design variables

Even though the result of the preceding section indicates that the importance level for the application of systematic procedures for accounting for design variables is "extremely important", the overall reliability of the procedures currently applied by the participating firms is not of equal strength. This may be because most of the participating firms uses simple ratio in accounting for design variables, which leads to haphazard assessment in the event of changes. Thus, improvements over the current practices are needed.

4.1.2.18 General Comments on ways of improving the accuracy of early cost estimates

Only two firms provided open-ended suggestions on ways of improving the accuracy of early cost estimates prepared for residential building projects. The suggestions are to:

1. Ensure informative clients who should be technically knowledgeable of the nature of his investment/project.
2. Establish an original scope for the work.
3. Maintain good quality while ensuring cost effectiveness
4. Ensure good material selections.

4.2 Empirical Analysis of Design Variables

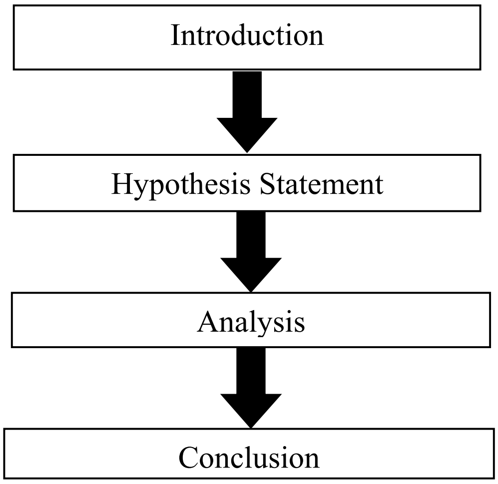
This section presents the results of the empirical analyses of design variables. The objective of the study is to investigate the cost implications of design variables to enable a more effective evaluation and implementation of a rudimentary cost benefit approach to future residential building projects.

The square meter of Gross Floor Area (GFA) method of expressing the cost of buildings is used for the analysis. This is because it is the most convenient and the most widely used in cost comparisons and cost planning. It is calculated by dividing the net cost of the building (excluding site works, cost of land, etc.) by the square meter of building area measured between the main enclosing walls, staircases and circulation space.

It is not uncommon to find for example, two or more residential buildings that are designed to meet the same needs, in relatively the same location, and of the same size and quality costing different amounts. This means that, their costs per m^2 of floor area are different. This study will provide a guide that will ensure a proper understanding of such discrepancies in a more meaningful way.

The data that will be used for these analyses are those formulated and explained in section 3.3, which entails preparation of cost estimate, changing of design variables and analyses of the changes observed. The procedure that will be followed in analyzing the cost implications of design variables is as given in Figure 4.21:

Figure 4.21: Procedure for the Empirical Analyses



4.2.1 Building Plan Shape

Introduction

It should be borne in mind that the shape of a building is usually dictated by the following factors:

b. Shape of the plot.

c. Function to which the building will be put.

d. Economics, which is reflected by the taste of the owner.

Under this section, the analysis of the existing plan shape indices was conducted, the influence of varying the layout of the building plan on the cost per square meter GFA and the total construction cost were investigated, and test of significance of the various plan shape indices were also conducted.

Analyses of Existing Plan Shape Indices

Despite the fact that the existing indices are defined using different formulae, they however, share common characteristics. First, the indices are all defined in terms of perimeter P and enclosed area A of the floor plan, both of which can be measured from the sketch plans and are thus available early in the design development stage. The rationale is that the exterior wall (which is determined by P) is usually an expensive component. Thus, any change in the plan shape, which results in an increase in the quantity of the exterior wall per unit of floor area, will result in an increase in unit construction cost C defined in terms of construction cost per floor area.

Since, prior knowledge suggests that the effects of A on C and that of P on C are opposite (i.e. other things being equal, an increase in P results in an increase in C while an increase in A results in a decrease in C, as demonstrated later) any plan shape index S should be defined in a way to reflect such characteristics. In other words, the effects of A and P on S must be opposite in direction. The existing indices are each considered below and the mathematical analyses confirm the assertion that the effects of A and P on S are indeed in opposite direction:

1. Perimeter to Floor ratio $R = \frac{WA}{A} = \frac{Ph}{A}$ . .. . (4.1)

where WA = wall area, A = floor area, P = perimeter of the building and h is the storey height.

$$\frac{\partial R}{\partial P} = \frac{h}{A} > 0$$

$$\frac{\partial R}{\partial A} = -\frac{Ph}{A^2} < 0 \text{ since } P, h > 0$$

2. Cooke's shape efficiency index JC = $\dfrac{P}{4\sqrt{A}} - 1$ . .. .. (4.2)

$$\frac{\partial JC}{\partial P} = \frac{1}{4\sqrt{A}} \quad > \quad 0$$

$$\frac{\partial JC}{\partial A} = \frac{P}{8A^{3/2}} \quad > 0$$

3. Plan compactness ratio POP = $\dfrac{2\sqrt{\pi A}}{P}$ . .. . (4.3)

$$\frac{\partial POP}{\partial P} = -\frac{2\sqrt{\pi A}}{P^2} \quad < \quad 0$$

$$\frac{\partial POP}{\partial A} = \frac{\sqrt{\pi A^3}}{P} \quad > \quad 0$$

4. Length/Breadth index LBI = $\dfrac{P+\sqrt{P^2-16}}{P-\sqrt{P^2-16}}$ . .. . (4.4)

$$\frac{\partial LBI}{\partial P} = \frac{2P}{16A}\left(2 + \frac{1}{\sqrt{P^2-16}}\right) \quad > 0$$

$$\frac{\partial LBI}{\partial A} = -\frac{16P}{(P-\sqrt{P^2-16})^2\sqrt{P^2-16}} \quad < 0$$

provided that positive real solution exist for both length and breadth i.e. $P^2 - 16A > 0$, and

(P- $\sqrt{P^2-16}$) > 0.

Hypotheses

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 farther a plan layout tends from a square shape, the higher the wall to floor area, cost per square meter GFA and total construction cost.

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

Analyses

The results of the detail investigation of the effect of plan shape on construction cost per square meter of GFA, partitioned into regular and irregular shapes, are presented in the following sections. The results obtained are limited to the method of construction prescribed in the 'typical villa'.

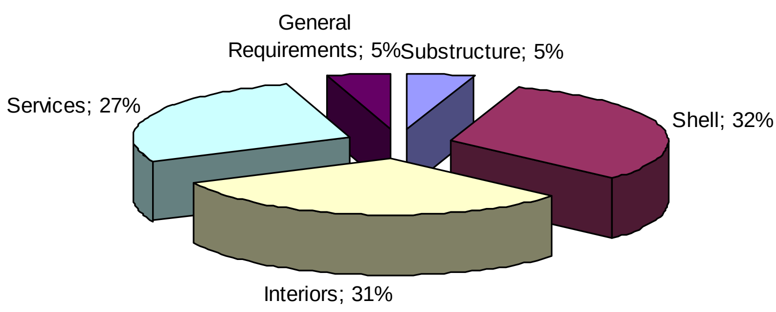
Regular Shapes

In order to obtain a Gross Floor Area of $600m^2$ on two floors ($300m^2$ per floor), several regular shaped layout options are possible. Consider three options represented diagrammatically in Appendix B: Layout A (base case), Layout B and Layout C.

Case A:

This is the base case having exterior dimensions of 15m x 20m per floor having a bay size of 5m x 5m. This is the case against which, the other two variant cases considered will be compared. The cost distributions amongst the various elements were shown in Table 3.2 and represented in Figure 4.22. It can be seen that structure and services components respectively constitute about 68% and 27% of the total building cost. The perimeter to floor ratio of this layout is: $= \frac{WA}{A} = \frac{Ph}{A} = \frac{[(20+15)*2*2]*3}{20*15*2} = \frac{420}{600} = 0.70$

Figure 4.22: Elemental Cost Distribution for Case A



Case B:

In this case, the average bay size is maintained but the exterior dimensions varied to 10m x 30m. The cost distribution changes, as shown in Table 4.11. The length and consequently the area of the exterior wall have increased by more than 14% over those of the base case.

Both the total cost and the cost per square meter GFA have increased by 3.5% over the base case. The perimeter to floor ratio of this layout is:

$$= \frac{WA}{A} = \frac{Ph}{A} = \frac{[(30+10)*2*2]*3}{30*10*2} = \frac{480}{600} = 0.80$$

Case C:

In this case, the average bay size is also maintained but the exterior dimension varied to 5m x 60m. The cost distribution also changed, as shown in Table 4.12. The length and consequently the area of the exterior wall have increased by more than 85% over those of the base case. Both the total cost and the cost per square meter GFA have increased by 20%. The perimeter to floor ratio of this layout is:

$$= \frac{WA}{A} = \frac{Ph}{A} = \frac{[(60+5)*2*2]*3}{60*5*2} = \frac{780}{600} = 1.30$$

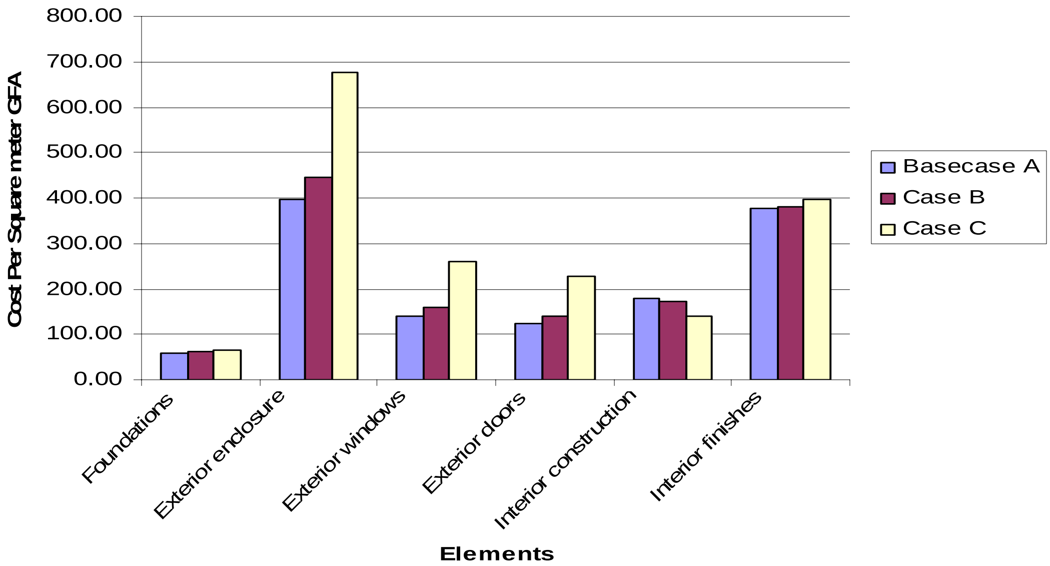
Generally, from the distributions of the elemental costs/m^2 GFA in Tables 4.11 and 4.12 against Table 3.2, it can be seen that the cost/m^2 are constant for the horizontal elements such as roof and floor elements but the elemental costs/m^2 for the vertical elements such as the exterior and interior walls together with their associated finishes and services (heating, cooling and plumbing), changes.

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 Table 4.13 and Figure 4.23 below.

TABLE 4.13: Comparison of variation in Cost per square meter GFA

Element	**Base case A**	**Case B**	**Case C**
Foundations	59.34	60.28	64.98
Exterior enclosure	398.29	444.73	676.90
Exterior windows	139.44	159.36	258.96
Exterior doors	122.01	139.44	226.59
Interior construction	178.68	172.08	139.08
Interior finishes	378.85	381.57	395.17

Figure 4.23: Variation in Elemental Cost per Square meter GFA



It can be seen that the greatest variation occurred in the walling systems. The increased exterior wall system for Case C has necessitated increased exterior door and window requirements but with subsequent reduction in quantity of interior partition. However, the costs per square meter GFA for interior finishes have slightly risen because of the increased inner surface of the exterior wall. The exterior wall construction cost per square meter GFA for Case C is still higher than those of Cases A and B by 14% and 11% respectively because of increased perimeter to floor ratios and the high expense involved with the exterior wall construction. It should be noted that Case C layout is narrower and deviates from a square shape far more than the other layouts considered. Thus, it can be concluded that on the basis of 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 above analyses indicate that the exterior wall system is the most affected element arising from changes in building plan layout, the analysis of the irregular shapes will be restricted to perimeter to floor ratio and cost differentials arising there from. The case A layout is still taken as the base case for this analysis. Note that both plans for Cases D and E have exactly the same floor areas as the base case, yet they are far more expensive due to the variation in the shape of their plan layouts.

Case D:

The layout D, as shown in Appendix B, is somewhat similar to layout A. the cost estimate for this layout, given in Table 4.14 indicates that the exterior perimeter has increased by

9% due to the irregularity of its outline even though they enclose the same floor area. Considering an average storey height of 3m, the perimeter to floor ratio of this layout is:

$$= \frac{WA}{A} = \frac{Ph}{A} = \frac{(76*2)*3}{300*2} = \frac{456}{600} = 0.76$$

Reasons for the increase in costs include the fact that layout D has higher wall to floor area ratio requiring 9% more external walling to enclose the same floor area than layout A. Other elements that are affected includes setting out, excavations (if strip foundations), drainage (due to extra manholes and extra length of piping needed). These have resulted in about 4% rise in cost over the base case.

Case E:

The layout E, shown in Appendix B, has a more complicated outline compared to even Case D. Its exterior perimeter has increased by 45% and 57% over those of Cases D and A respectively even though they enclose the same floor area. The cost estimate for this layout is shown in Table 4.15. Considering an average storey height of 3m, the perimeter to floor ratio of this layout is:

$$= \frac{WA}{A} = \frac{Ph}{A} = \frac{(110*2)*3}{300*2} = \frac{660}{600} = 1.10$$

Reasons for the increase in costs are because layout E has much higher exterior wall to floor area ratios compared to Cases A and D requiring more external walling to enclose the same floor area. Other elements that are affected includes setting out, excavations (if strip foundations), drainage (due to extra manholes and extra length of piping needed). These have resulted in about 12% rise in cost over the base case. This shows that increased irregularity in the plan outlines of buildings add to their cost per square meter GFA and hence their overall costs.

A closer examination of the cost analyses also reveals that the ratio of the elemental cost of the walls is the same as the ratio of the wall areas. It is thus possible to predict the cost of wall for say, shape B, from the elemental cost/m^2 of wall for shape A together with the measurements of the wall areas. Table 4.16 shows the summary of the relationship between floor area, perimeter floor ratio and consequently the cost of the various building layout options, but this time using a square shape as a base.

TABLE 4.16: Relationship between Floor area and Cost of Exterior cladding

Layout	Area of exterior cladding (m^2)	Floor area (m^2)	Perimeter floor ratio	Relative cost: Base = square shape
17.32mx17.32m	415.68	600	0.69	100
A	420	600	0.70	101
B	480	600	0.80	116
C	780	600	1.30	188
D	456	600	0.76	110
E	660	600	1.10	159

The table demonstrates that the more compact a plan shape and the nearer it is to the square shape, the more economical it is, both in terms of areas (and hence cost) of the exterior cladding elements and the entire building. It can also be further discerned that a rectangular building having only four external corner columns (such as layout A) is more economical than an irregular shape (such as layout E) having numerous corner columns. The reason being that an external corner column carries only a quarter of a bay and is eccentrically loaded, thereby making it less economical.

Development of Model

If plan shape index S is a predictor of unit construction cost C (cost per square meter GFA), then C must be a function of S and some other variables i.e. $C = f(S, X_i)$ (4.5)

Where X_i's are design variables that are independent of S, such as total height H, or number of storeys, N.

The individual marginal effects of P and A on C are given by the partial derivatives of P and A on C, respectively given below:

$$\frac{\partial C}{\partial P} = \frac{\partial C}{\partial S}\frac{\partial S}{\partial P} \text{ and } \frac{\partial C}{\partial A} = \frac{\partial C}{\partial S}\frac{\partial S}{\partial A}$$

These combine to give $\frac{\partial C}{\partial P}\Big/\frac{\partial C}{\partial A} = \frac{\partial S}{\partial P}\Big/\frac{\partial S}{\partial A}$ (4.6)

The left hand side of the above equation gives the ratio of the marginal effects of A on C to that of P on C.

But by definition, S is a function of P and A: i.e. $S = f(P, A)$

$$S = \frac{P}{A} \tag{4.7}$$

Such that $\frac{\partial S}{\partial P}=\frac{1}{A}$ and $\frac{\partial S}{\partial A}=-\frac{P}{A^2}$

Equation 4.6 therefore becomes: $\frac{\partial C}{\partial A}\bigg/\frac{\partial C}{\partial P}=-\frac{P}{A}$ (4.8)

which means that the ratio of the marginal effect of *A* on *C* to that of *P* on *C* is equal to the negative of the plan shape index. This further clarifies the directional relationship between *C, P* and *A* in the indices.

By dividing both sides by *C* and re-arranging, equation 4.8 can be transformed to:

$$\frac{\partial C}{U}\bigg/\frac{\partial A}{A}=-\frac{\partial C}{U}\bigg/\frac{\partial P}{P} \qquad (4.9)$$

which means the unit construction cost per square meter GFA, *C,* remains unchanged if the percentage changes, both in terms of sign and magnitude, in *A* and *P* are equal. This is because equation 4.9 shows that the effect on *C* due to an increase in *A* can be offset by an increase of equal amount in *P*.

Substituting *S* by *P* and *A* in (4.5),

$$C = f\,(P, A, X_i) \qquad (4.10)$$

Equation 4.10 is thus a building shape model for predicting the cost per square meter GFA.

However, note that there is no any prior knowledge of the functional relationship between unit construction cost *C* and design variables. Thus, regression modeling, which has been successfully used by other construction researchers (Russell and Jaselskis 1992; Diekmann and Girard 1995; Molenaar and Songer 1998; Ling 2002) when there is evidence that one or more explanatory variables (independent variables) cause another variable (dependent variable) to change, will be used.

The particular form of regression models used here are the classic linear models. The following models are estimated using the ordinary least-squares technique:

1. $Y_i = \alpha + \beta_1 X_{1i} + \beta_2 X_{2i} + \varepsilon_i$ (4.11)

   where, Y = value of dependent variable expressed in SR/m^2 GFA; α = constant, and the intercept at the Y axis; β_1 and β_2 are regression coefficients; X_1 and X_2 are values of independent or explanatory variables, in this case shape indices, *S,* and design variable that is independent of *S* (Height or Number of storeys); ε_i = error term. It should be noted that each of the shape indices, *S,* is a form of interaction between *A* and *P*.

2. $Y_i = \alpha + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \varepsilon_i$ (4.12)

   where, Y = value of dependent variable expressed in SR/m^2 GFA; α = constant, and the intercept at the Y axis; $\beta_{1,}$ β_2 and β_3 are regression coefficients; $X_{1,}$ X_2 and X_3 are values of independent or explanatory variables , in this case *P*, *A* and design variable that is independent of *S* (Height or Number of storeys); ε_i = error term.

The summary of the comparison of goodness of fit of the models are provided in Table 4.17.

TABLE 4.17: Regression results of separately using P and A, and plan shape indices as regressors

	P & A	**R**	**JC**	**POP**	**LB1**
Constant	3450.120 (21.076)	2726.133 (70.055)	3135.106 (38.499)	44410.590 (20.545)	3065.796 (38.605)
H/N	2.096* (0.126)	-9.586* (-1.376)	62.567 (4.133)	66.659 (3.732)	61.490 (4.259)
A	-2.067 (-9.122)				
P	10.230 (12.012)				
R		1206.055 (21.002)			
JC			775.172 (7.500)		
POP				-1480.383 (-6.134)	
LBI					64.779 (7.928)
R^2	0.966	0.985	0.899	0.858	0.908
Adjusted R^2	0.954	0.982	0.876	0.827	0.888
Chau's Adj. R^2	0.251	0.0168	0.0776	0.0378	0.0643
p-value	0.0000	0.0000	0.00003	0.00015	0.00002

* Not significant at 5%
Figures in parentheses are absolute *t*-statistics

The results show that most of the independent variables are significant at 5% level. The results remained the same using either *H* or *N* as the independent variable that does not relate to the plans shape.

Regression model is an iterative process and the predictive power of the model is judged through the statistical measurement called coefficient of determination (R^2), which is a measure of goodness of fit for the model. The R^2 is used to measure the strength of the correlation when more than two variables are being analyzed, by giving the proportion of the variance of dependent variable, which is explained by independent variables, reflecting the overall accuracy of the predictions. However, when the number of independent variables in increased, R^2also increases. A better estimate of the model goodness of fit is *adjusted* R^2. Unlike R^2, it does not inevitably increase as the number of included independent variables increases. The high *adjusted*-R^2 values indicate that variations in construction cost per square meter of GFA, C, are overwhelmingly explained by the various independent variables considered. This further provides internal validity to the data used for the analyses. The low *adjusted* R^2 obtained by Chau (1999) may be attributable to the use of project types with widely varying characteristics in terms of size, components and specifications, as factors other than shape may have significantly contributed to the variations in costs/m^2 GFA of the buildings used in the models. The excel summary outputs for the regression analyses are provided in Tables 1 – 5 in Appendix D.

Conclusions

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 farther 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 (more complicated) the building plan shape, the lower (higher) the cost per unit GFA for that building.
3. The effect of layout narrowness on the perimeter to floor ratio and consequently cost per square meter GFA and overall cost is greater than the effect of layout irregularity.

Thus, the hypotheses are all true and are all accepted.

4.2.2 Building size

Introduction

Size is one first items considered in connection with any construction project. It should be borne in mind that the designer may only have little influence over the size of a project as this generally decided by the clients' needs. Nevertheless, the proper understanding of cost-related matters becomes important since Seeley (1996), and Ferry and Brandon (1991) have since reported that costs may not vary in proportion to changes in size. The intuitive reasons advanced for this follows the economic theory of economies of scale and includes the following:

1. Longer time per unit is required to design smaller buildings than larger buildings, and this is reflected in design costs.
2. Designers' fees, especially in the United Kingdom (UK) and most of the other commonwealth and European countries, are calculated on a sliding scale of charges.
3. Shorter duration for larger buildings as a result of higher management efficiency. If a resident engineer is engaged, better organizational ability and improvement in the outputs of operatives are expected.
4. More intensive use of plants for the larger buildings is possible.
5. Better capability of obtaining improved discounts on materials for the larger buildings is possible.

This study, while agreeing with all the above assertions will analyze building size in terms of perimeter to floor ratio.

Hypothesis

1. The larger the plan area for a given shape, the lower the perimeter/floor ratio. That is, larger buildings have lower unit costs (per square meter GFA) than smaller-sized buildings offering an equivalent quality of specification.

Analysis

Suppose that both the length and width of base case A layout is sequentially increased by a multiple of 2 up to 10 and on two floors with an average of 3m ceiling height, the variation in the perimeter to floor ratio with building size is illustrated in Table 4.18 below:

TABLE 4.18: Variation in Perimeter to Floor Ratio with Building size

Length (m)	Width (m)	Plan area (m^2)	Wall area (m^2)	Perimeter to Floor ratio
15	20	600	420	0.70
30	40	2400	840	0.35
45	60	5400	1260	0.23
60	80	9600	1680	0.18
75	100	15000	2100	0.14
90	120	21600	2520	0.12
105	140	29400	2940	0.10
120	160	38400	3360	0.09
135	180	48600	3780	0.08
150	200	60000	4200	0.07

Comparing layout A with a similarly but larger layout, such as the one with external dimensions of 150mx200m, shows that building A is proportionately more expensive as far as the amount of external cladding is concerned by $\frac{0.63}{0.07}x100 = 900\%$. A graphical representation of the relationship between the perimeter to floor ratio and building size is illustrated in Figure 4.24.

Figure 4.24: Variation of Perimeter to Floor ratio with Building size

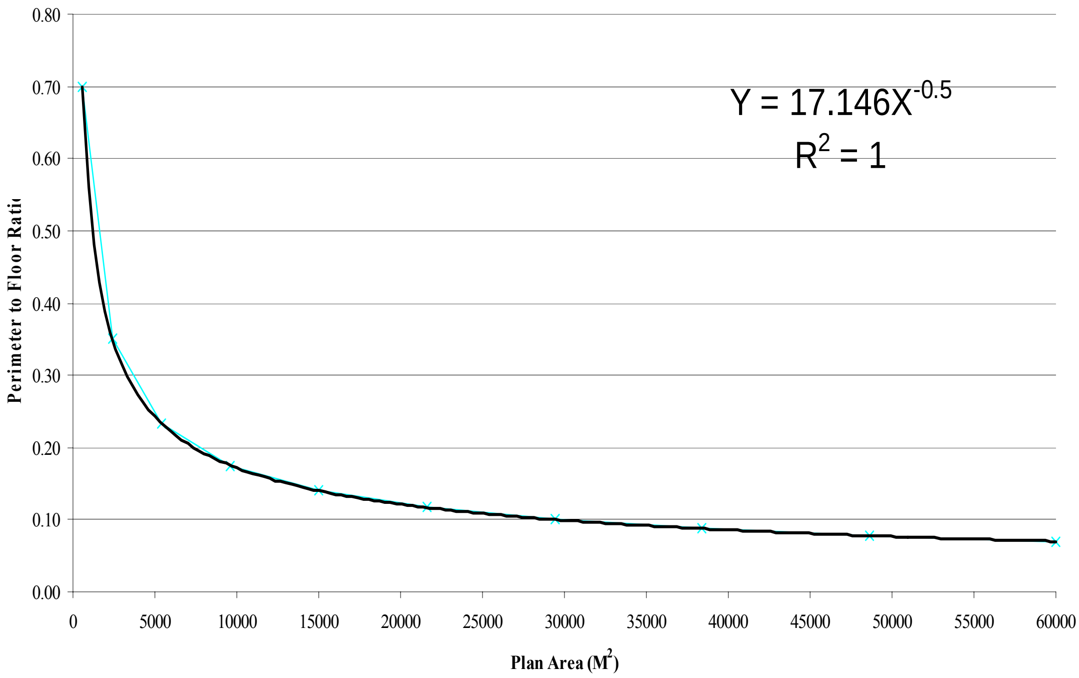


Figure 4.24 shows an inverse relationship exists between the Perimeter to Floor ratio and size of building plan. A power relationship provides coefficient of regression of unity, which indicates that it can be used as a good estimate for changes in the variables. However, direct linear relationship exists between the Perimeter to Floor ratio and the cost per square meter GFA, as shown in Figure 4.25. It thus follows that an inverse relationship is expected between building size and the cost per square meter GFA as shown in Figure 4.26 with power relationship being the most significant – see Tables 6 to 14 of Appendix D.

Figure 4.25: Variation of Perimeter to Floor ratio with Building Cost Per M^2 GFA

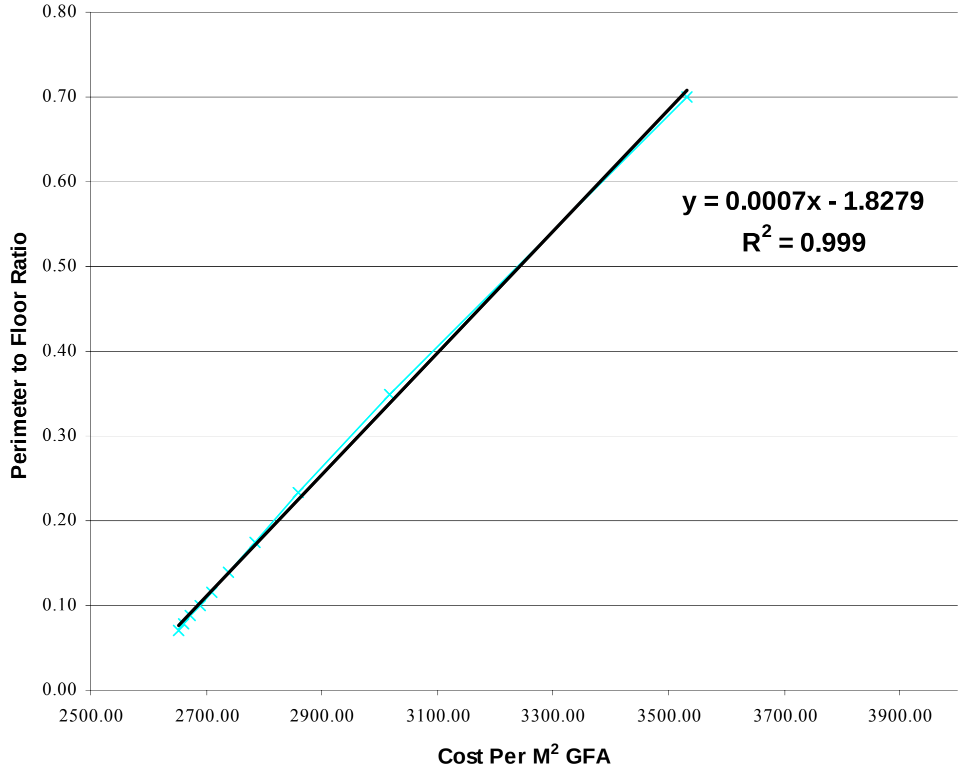
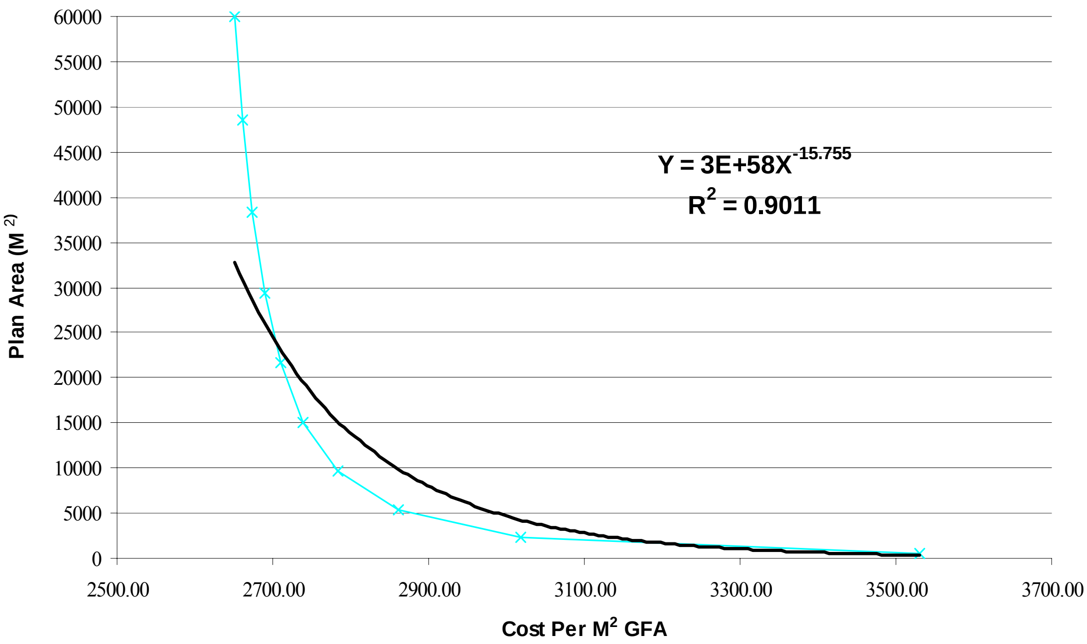


Figure 4.26: Variation of Building Size with Cost per M^2 GFA



Note that if the equation given in Figure 4.26 is properly fitted, the equation of the form $\mathbf{Y = aX^b}$ gives a = 2.83157E+058 and b = -15.75508.

Conclusions

1. It can be concluded that where a choice is to be made between enclosing an area in one large building and in two or more smaller buildings, in so far as the external cladding elements are concerned it will be more economical to provide the accommodation in the larger building. However, deeper analyses of the lighting and servicing requirements needs to be undertaken in order to accurately qualify the conclusion above.

2. The relationship between Perimeter to Floor ratio and Building is given by the equation: $\mathbf{Y = 17.149X^{-0.5}}$, where Y = Perimeter to Floor ratio and X = Building size.

3. The relationship between Perimeter to Floor ratio and the Construction cost per square meter GFA is given by the equation: $\mathbf{Y = 0.0007X - 1.8279}$, where Y = Perimeter to Floor ratio and X = Cost per square meter GFA.

4. The relationship between Building size and the Construction cost per square meter GFA is given by the equation: $\mathbf{Y = 3E{+}58X^{-15.755}}$, where Y = Building size and X = Cost per square meter GFA. This equation can be put in a reverse order as $\mathbf{Y = 4834.8X^{-0.0572}}$, where Y = Cost per square meter GFA and X = Building size.

Thus, the earlier stated hypothesis is true and accepted.

4.2.3 Storey height

Introduction

The storey height of a building is largely determined by the needs of the users. A greater height than is necessary may however be required to provide satisfaction of peculiar needs.

Hypothesis

1. The higher the average storey height of a building, the higher the cost per square meter GFA.

Analyses

Like the building plan shape, the storey height of a building affects its vertical elements, both internally and externally. It also affects to some extent the services costs, particularly cooling and heating, due to increased volume of the building.

Figure 4.27 shows the relationship between the average storey height and cost per square meter GFA. The values of the average heights considered were 20% successive increments over the original 3m storey height. The elemental cost estimates are given in Tables 15 – 17 of Appendix D.

Figure 4.27: Variation of Cost/M^2 with Increase in Average Storey Height

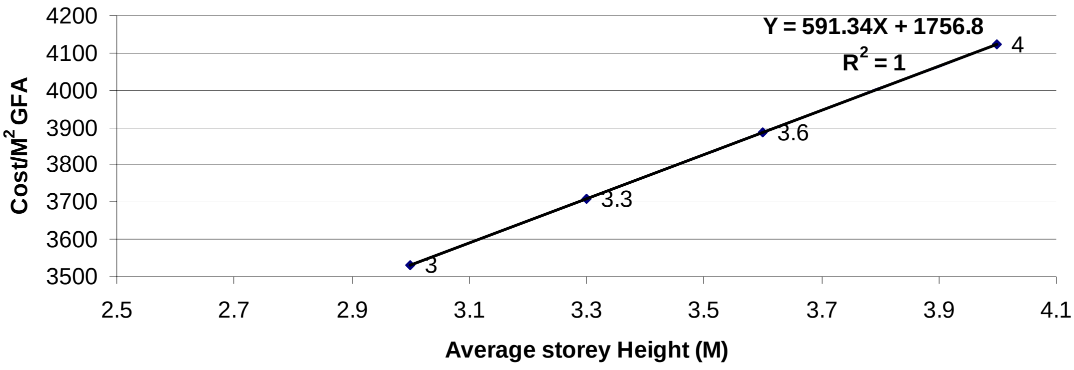
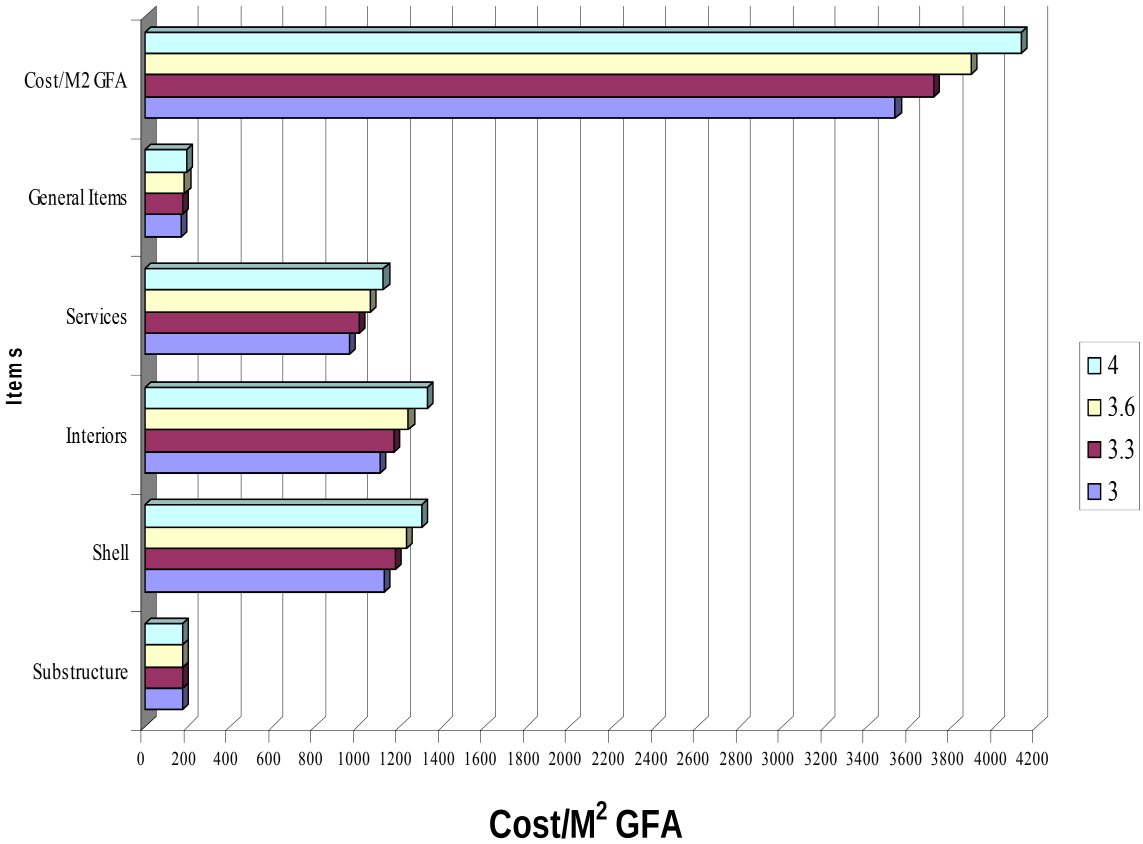


Figure 4.28 shows the variation in the cost/m^2 for the major components as the average storey heights were increased.

Figure 4.28: Effect of Increase in Height



It can be seen from Figure 4.28 that the vertical components are the most affected by the variation in average storey height. The effect of storey height on the external cladding elements will be demonstrated by re-examining and comparing the building plan shapes A, B, and C while considering 20% successive increments over the original 3m storey height.

Table 4.19 sets out the results of the comparison and reveals the importance of examining both plan shape and storey height, together with the area of the building, before concluding that a particular design is economic or otherwise. All the other factors staying constant, the costs per square meter of GFA and perimeter to floor ratio of high-storeyed buildings are higher than those of lower-storeyed buildings. The cost of the vertical elements are affected in direct relation to the change in storey height i.e. as reflected in the last set of columns of Table 4.19, relative to the base case (layout A).

TABLE 4.19: Comparison of Effects of Variations in Average Storey heights

Shape	Area of Exterior cladding, m^2				Floor area, m^2	Ratio of Exterior cladding to Floor area				Relative cost: Base plan A x 3m high = 100			
	3m	**3.3m**	**3.6m**	**4.0m**		**3m**	**3.3m**	**3.6m**	**4.0m**	**3.0m**	**3.3m**	**3.6m**	**4.0m**
Plan A	420	462	504	560	600	0.70	0.77	0.84	0.93	100	110	120	133
Plan B	480	528	576	640	600	0.80	0.88	0.96	1.07	114	126	137	153
Plan C	780	858	936	1040	600	1.30	1.43	1.56	1.73	186	204	223	247

Conclusions

1. The perimeter to floor ratio increases with the average storey height.
2. The cost per square meter GFA increases with the average storey height of a building.
3. The relationship between Construction cost per square meter GFA and Average storey height of a building is given by the equation: $\mathbf{Y = 591.34X - 1756.8}$, where Y = Cost per square meter GFA and X = Average storey height.

Thus, the hypotheses are all true and accepted.

4.2.4 Total building height

Introduction

The cost relationship between single and multi-storey construction will not be revealed by the simple examination of cost analysis, which gives costs expressed per square meter of GFA of the building. This is because clients are more interested in the total usable floor area rather than the total gross floor area. Although, toilet areas, corridors, staircases, entrance hall, plant rooms, etc., are necessary for the proper functioning of buildings, they are of little real value to the client especially in commercial and residential apartment designed to be used for commercial purpose. In fact the best value for money will be obtained by keeping the difference between the gross floor area and the net usable floor area (usually called the circulation area) to the absolute minimum.

Hypothesis

1. The construction costs per square meter GFA of tall structures are greater than those of low-rise buildings offering similar quality of specification.

Analyses

The effect of an increase in the number of storeys on the relation between net usable and gross floor areas will be examined in the following example. Note that the gross floor area of a two-storey building would be twice that of a single storey building having the same floor dimensions, but the introduction of a staircase would cause a reduction in the net usable area. Therefore, even though their costs/m^2 GFA would be similar, the cost for providing the net usable area may be very different. For example:

Single-storey (with external dimensions of 15mx20m on a single floor):

Gross Floor Area	=	300m^2
Cost/m^2 GFA	=	SR3, 537.51 (from Table 21 of Appendix D)
Net Usable Area (NUA)	=	262.50 m^2
Cost/m^2 NUA	=	SR4, 042.87

Two storeys (Base case A):

Gross Floor Area	=	600m^2
Cost/m^2 GFA	=	SR3, 530.81
Net Usable Area (NUA)	=	465m^2
Cost/m^2 NUA	=	SR4, 555.88 (an increase of about 13% over the single storey)

The scenario is however different if the entire 600m^2 were to be built on a single storey as indicated in Tables 18 – 21 of Appendix D, where the range of increment of cost/m^2 NUA rises up to 21% above the base case A.

On the other hand, if square-shaped layouts each consisting of a total floor area of 600m^2 were considered, the cost estimates that are shown in Tables 22 – 24 of Appendix D indicates that the two-storey building has a 7.6% increase in cost/m^2 GFA over the single-storey construction. However, the three-storey building has an increase of 2.7% over the two-storey but a 10.5% increase over the single-storey construction.

The effect of changing construction method beyond two-storeys on the relationship between net usable and gross floor areas would probably not be as great as the change from single- to a two-storey construction, as staircase would be a constant feature of the plan until the form of construction and safety codes necessitates additional staircase, lift or changes in foundations and framework.

In summary, the cost distributions shows division of the components' costs into four groups; those which:

1. Fall as the number of storeys increases – foundations, roof
2. Rise as the number of storeys increase – lift installations, frame
3. Are unaffected by the number of storeys – floor finishes, ceiling finishes
4. Fall initially and then rise as the number of storeys increases – exterior enclosure.

Conclusions

1. Given the same layout, the construction costs per square meter GFA of a single storey is similar to that of a two-storey building. However, above certain number of floors, the cost per square meter GFA of tall structures are greater than those of low-rise buildings offering similar amount of accommodation and specifications.
2. Given the same shape of layout, amount of accommodation, height and quality of specifications, increase in the construction costs per square meter NUA is higher than increase in the cost per square meter GFA as a result of increasing the number of storeys. Thus, tall structures would only be preferred only where land is either expensive or in scarce supply.
3. The cost per square meter of Net Floor Area increases with number of floors.

Thus, the stated hypothesis is true and accepted.

4.2.5 Elemental Cost Analyses

The elemental costs of the major components of the single storey construction will be compared with those of multi-storey constructions of up to three storeys to demonstrate the effect of alternative forms of construction. The comparison will be done following the Uniformat II system classification, as used in the cost estimate model.

The comparison will involve square-shaped buildings designed on one (S), two (T) and three H storeys. Their cost estimates are as shown in Tables 22, 23 and 24 of Appendix D.

Substructure

Generally, the sizing of the isolated foundation bases varies in proportion to the amount of load being carried by a building. Thus, the sizes increase as more upper floors are being introduced. However, there is little or no difference in the sizing of the bases between one- and three-storey constructions.

Foundation slab, on the other hand, has a constant unit rate but its cost in terms of cost per square meter of GFA will fall by a factor of 2 and 3 upon the addition of the one floor over buildings S and T respectively.

The substructure cost, as a percentage of the total construction cost, dropped from 10.46% to 4.99% and to 3.30% due to the additional one and two floors respectively.

Shell

The cost of *upper floors* varies directly with the rate of change of the ratio of upper floor area to the total floor area, the thicknesses of the upper floors being a function of the clear span.

The cost per square meter GFA of the *roof* element (comprising of the roof structure and the roof covering), like the upper floors, varies in line with the rate of change of roof area to total floor area.

Frame (network of columns and beams) may not be necessary for building S, but as loads imposed by adding successive upper floors increase, costs generally tend to rise too. Like the foundation costs, the cost of frame changes at rates determined by two independent factors, i.e. horizontal and vertical loadings:

1. The addition of upper floors requiring supporting beams varies at the rate of change in the ratio of upper floor area to total floor area. Thus, between buildings S and T, the change is from SR64.80 to SR69.36 per square meter of GFA (representing a 7.5% rise) whereas between buildings T and H there is a further 5% rise in the cost per square meter GFA.
2. The additional loading on the columns requires strengthening of the columns or reduction of the bay sizes as the number of floors carried increase. The change for column costs between buildings S and T is from SR26.01to SR29.76 per square meter of GFA (representing over 14% rise) whereas between buildings T and H a further 10% rise occurred. Reduction of the bay sizes from 5mx5m to 4mx4m for both buildings T and H leads to 10% increment in the cost per square meter of GFA. The cost estimate for the 4mx4m bay sizes for buildings T and H are respectively shown in Tables 25 and 26 of Appendix D.

The cost per square meter GFA of the external cladding, which comprises of the exterior walls, windows and the exterior doors vary according to the size and layout of the buildings, the number of storeys and the storey height. The nature of the variations in these elements in particular depends mainly on:

1. Whether the total floor area remains constant, or
2. Whether the total floor area changes while the plan area remains constant.

If the first condition applies, the ratio of the area of the element to floor area will change appreciably because of the principle discussed earlier in section 4.2.2, i.e. where small buildings were found to require higher proportion of external cladding elements to floor area than larger buildings.

If however the second condition applies, the change in the ratio of the element to floor area is minimal, with only a change in the storey height being capable of causing an appreciable change.

The effect of increasing glazed area would depend on the cost differential between exterior wall system and the glazing.

Interiors

The partitions are the internal elements that are mostly affected by changes in the plan shape, although the nature of the effect is difficult to assess with any accuracy as it depends a great deal upon the type of building being considered. Residential buildings have very high density of internal partitioning which enables the provision of large number of small rooms, unlike say, factory buildings. If the detailed cost analyses of the residential buildings considered are examined, it can be seen that as the perimeter to floor ratio changes, so also does the internal partition to floor ratio but in the opposite direction. The costs of the changes to all intents and purposes would exactly compensate each other provided that the unit costs of exterior and interior walls are the same.

The cost of the interior doors is controlled by the same factor as the interior partitions.

Obviously, no staircases are required in a single storey building, but at least one staircase will be required in the multi-storey construction. In fact, fire escape requirements would even necessitate the provision of additional staircase for storeys above two, thereby significantly reducing the net usable area of the building. The costs per square meter of GFA for staircase in two and three storey constructions are reasonably constant and an economic planning would provide a reasonably constant level of utilization.

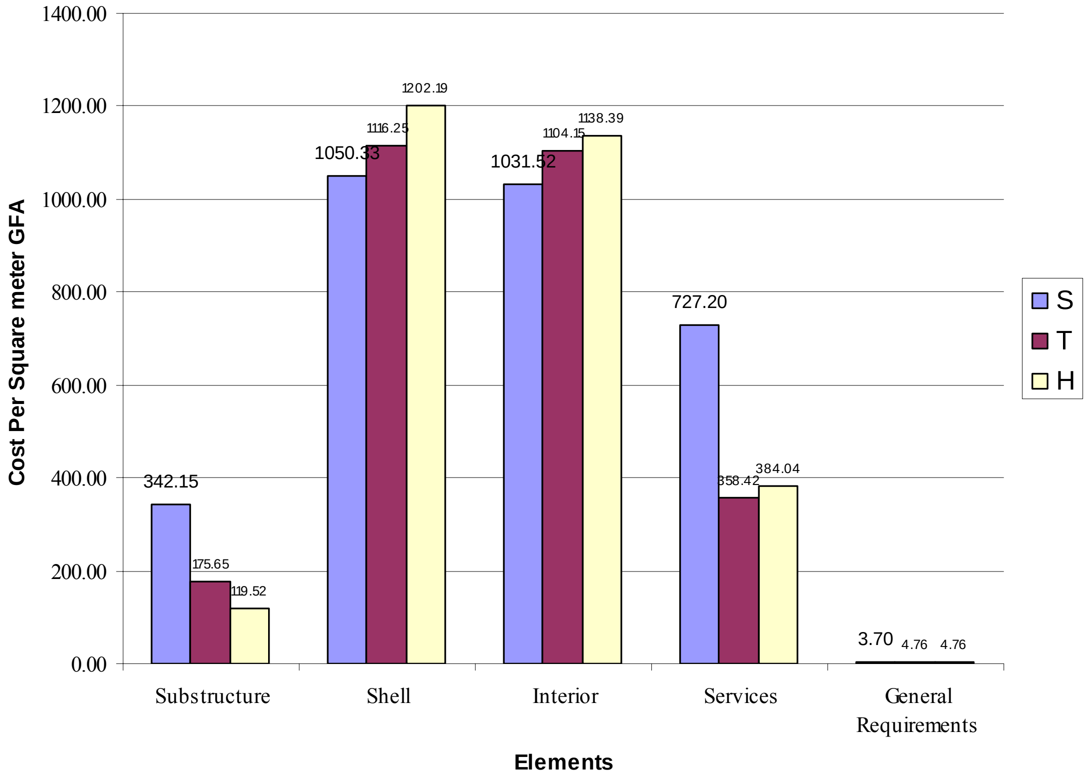
The finishes and decorations applied to the exterior walls and interior partitions will be affected in the same manner as the elements themselves. However, floor and ceiling elements, being horizontal in the building are directly related to the floor area and therefore changes as the floor area changes.

Services

The effect on cost of services due to the addition of another floor is little. The cost would only jump up beyond three storeys when the provision of lift, scaffolding and additional insurance becomes necessary.

The distribution of cost per square meter GFA amongst the major components of the three buildings used for analysis in provided in Figure 4.29.

Figure 4.29: Distribution of Elemental Cost per Square meter GFA



It can be seen from the Figure that while the cost per square meter GFA decreases with increasing storeys; shell, interiors and general requirements increases with storey but with different degrees. On the other hand, services exhibit different characteristics, initially decreasing between first and second storey and then rising between second and the third floor. This may be attributed to the need to fulfill additional safety requirements due to the increase in the total building height.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.0 Introduction

This chapter presents the summary of the study, major conclusions drawn from the results of the study and appropriate recommendations suggested. Some recommendations for further studies were also made.

5.1 Summary of the Study

This research study was focused to achieve two major targets. After through review of relevant literature in order to gain insight into the research theme, the first target was to investigate the procedures adopted by A/E firms in accounting for design variables in the early cost estimates they prepare for residential buildings. This was achieved through the administration of questionnaire. Nineteen (19) firms participated in the survey. The key issues addressed include the investigation of:

1. The techniques used for determining the early cost estimates of residential buildings.

2. The factors influencing the choice of the technique and the evaluation of the A/E firms about the technique used.
3. The procedures adopted for accounting for design variables in the early cost estimates.

The second target was concerned with the empirical study of the effects of design variables on the cost of residential building in a series of simulation experiments. The study was limited to design variables that are architectural in nature. Empirical Cost estimate model of a "typical Saudi Arabian villa" was prepared and used for the simulation. The effects of the other factors on construction cost were held constant during the simulation runs and conclusions to a number of hypotheses formulated, among other things, were sought from the results of the simulation runs.

5.2 Conclusions

The major conclusions that can be drawn from the results obtained from both the questionnaire survey and simulation experiments presented in chapter four are being summarized under relevant headings below:

Survey of A/E firms

1. Most of the respondents and the firms they work for have very long experience in construction business. All the participating firms offer both design and consultancy services; 36% industrial projects, 28% residential buildings, 26% commercial and 8% highway projects.

2. About 10% of the employees of the participating firms are working in the estimating department, and have over 10years average estimating experience.
3. The average value of residential projects handled by the participating firms is less than SR5 million, and majority are for private and semi-government clients, 90% of whom engage them for cost consultancy as part of the design package.
4. 84% of the participating firms do not use any specialized cost estimating software.
5. Only 47% of the participating firms prepare early cost estimates for their residential clients and the techniques used include the use of prevailing cost of square meter, approximate quantities method, database of similar projects and unit (time and work) rate.
6. Project size was given the highest rank as the most important factor that impact the decision of which estimating technique to utilize for early cost estimation. This was closely followed by the amount and quality of information available to the estimator about the project.
7. Comparison of the estimates prepared by the firms in previous projects with the eventual tender prices revealed that the estimating techniques used in preparing early cost estimates are “very reliable”.
8. The most important factors which impact the decision of the A/E firms on design variables are shape of the plot for plan shape; land cost for total number of storeys; intended use for average storey height; expected traffic for circulation space; owner’s wish for percentage of glazed area; and the percentage of the glazed area for building services.

9. The importance level for the application of constructability as a design tool was found to be “extremely important”.
10. The average allowance made in residential building designs for circulation space as a percentage of total floor area is 31.84%, glazed area as a percentage of total exterior wall area is 29.21%, and cost of M & E services as a percentage of total building cost is 23.95%.
11. 47% of the participating A/E firms use systematic procedures in accounting for design variables in the early cost estimates they prepare for residential buildings.
12. 11% and 44% of the firms respectively use Wall to floor ratio and other plan shape indices to account for plan shape in early cost estimates.
13. 11% and 89% of the firms respectively use detailed analysis and simple ratio to account for number of storeys and average storey height.
14. 67% and 33% of the firms respectively use detailed analysis and simple ratio to account for circulation space, glazed area, M&E services, and density of internal partition in early cost estimates.

    This literally implies that these firms do not use any of the models developed by researchers and have not developed any custom models for use in their firms.
15. Over-assessment of design variables in early cost estimates was found to be more severe than under-assessment, with loss of owner’s confidence in the A/E firm being the most severe consequence.

16. While the A/E firms acknowledge that the application of systematic procedures for accounting for design variables is “extremely important”, their rating of the overall reliability of the procedures currently applied is not of equal strength.

Simulation Results

1. Given the same size of accommodation and quality of specifications, the simpler (more complicated) the building plan shape, the lower (higher) its cost per square meter GFA.
2. Given the same size of accommodation and quality of specifications, 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 farther a plan layout tends from a square shape, the higher the perimeter to floor ratio, cost per square meter GFA and total construction cost.
3. The effect of layout narrowness on the perimeter to floor ratio and consequently cost per square meter GFA and overall cost is greater than the effect of layout irregularity.
4. The larger the plan area for a given shape, the lower the perimeter/floor ratio. That is, larger buildings have lower unit costs (per square meter GFA) than smaller-sized buildings offering an equivalent quality of specification.
5. The cost per square meter GFA increases with the average storey height of a building.
6. Given the same shape of layout, amount of accommodation, height and quality of specifications, increase in the construction costs per square meter NUA is higher

than increase in the cost per square meter GFA as a result of increasing the number of storeys. Thus, tall structures would only be preferred only where land is either expensive or in scarce supply.

7. Both the cost per square meter of Net Floor Area and cost per square meter GFA increase with number of floors.
8. The relationship between Perimeter to Floor ratio and Building is given by the equation: $\mathbf{Y = 17.149X^{-0.5}}$, where Y = Perimeter to Floor ratio and X = Building size.
9. The relationship between Perimeter to Floor ratio and the Construction cost per square meter GFA is given by the equation: $\mathbf{Y = 0.0007X - 1.8279}$, where Y = Perimeter to Floor ratio and X = Cost per square meter GFA.
10. The relationship between Building size and the Construction cost per square meter GFA is given by the equation: $\mathbf{Y = 3E{+}58X^{-15.755}}$, where Y = Building size and X = Cost per square meter GFA. This equation can be put in a reverse order as $\mathbf{Y = 4834.8X^{-0.0572}}$, where Y = Cost per square meter GFA and X = Building size.
11. The relationship between Construction cost per square meter GFA and Average storey height of a building is given by the equation: $\mathbf{Y = 591.34X - 1756.8}$, where Y = Cost per square meter GFA and X = Average storey height.

5.3 Recommendations

Based on the findings of this research discussed in chapter five and summarized in section 5.2, the following recommendations are being suggested:

1. Increased use of specialized cost estimating packages to enhance productivity and accuracy of the estimators.
2. Increased demand for early cost estimating services by clients to increase effective implementation of projects through efficient planning and control of resources throughout the project cycle.
3. Although the A/E firms are aware of the strategic importance, of the need to devise systematic procedures for accounting for design variables have poor attitude of implementing research findings or developing customized procedures. It is therefore, recommended that innovative practices be encouraged in the firms and efforts to implement research findings be inculcated in their various practices. This will also help in averting the consequences of over-assessment and under-assessment of the cost implications of design variables.
4. Given the constraints under which this study was carried out, the established relationships between the design variables can be adopted for use by Architectural/Engineering firms.

5.4 Recommendations for Further Studies

The following are areas of related interest, which if explored, would provide increased validity to the findings of this research:

1. With the increasing adoption of Design-Build project delivery system, it is hereby recommended that a similar questionnaire survey be administered on Design-Build contractors. Similarly, the opinions of estimating personnel working in Government agencies could also be sought on the procedures used in accounting for design variables in their early cost estimates.
2. The boundaries of the respondents could also be widened to include the whole Saudi Arabia and all types of building project.
3. Since the empirical study was limited to residential buildings, similar investigations can be carried out on industrial and commercial buildings and the results compared.

APPENDIX A

RESEARCH QUESTIONNAIRE

Section A: General information about respondent and firm:

This section contains questions seeking information about you and your organization. Please answer the questions either by writing the required information in the spaces provided or by placing a tick (√) against the option that corresponds to your choice.

1. Your Name (Optional)	
2. Status in the firm (Title)	
3. How long have you been working for this firm?	**Years**
4. Company Name (Optional)	
5. Company Telephone #	
6. Company Fax #	
7. Company e-mail address.	

8. For *how long* has this firm been in business in the construction industry?

A) Less than 5 years.	B) 5-10 years.
C) 10-15 years.	D) Over 15 years.

9. How many *employees* does this firm have in *total*?

A) Less than 50	B) 50 – 100.
C) 100 – 150.	D) Over 150.

10. How many *employees* are working in the *estimating unit* of this firm?

A) Less than 5.	B) 5 – 10.
C) 10 – 15.	D) Over 15.

11. What is the average *years of experience* of the unit employees as cost estimators?

A) Less than 5 years	B) 5 – 10 years.
C) 10 – 15 years.	D) Over 15 years.

12. What is the *category* of this firm?

A) Design only	B) Consultancy only.
C) Design and Consultancy.	D) Cost Estimating (Quantity Surveying) services only.

13. What type of *construction projects* does this firm work on (*in terms of number*)? Please indicate the approximate proportion for each type.

A) Residential buildings [ ]%	B) Commercial buildings [ ]%
C) Industrial/Engineering projects [ ]%	D) Highway construction [ ]%

14. What is the average *size* of residential building projects (in *monetary terms*) undertaken by this firm in the last five years?

A) Less than SR 5 million	B) SR 5 – 10 million
C) SR 10 – les than SR 20 million	D) Over SR 20 million.

15. Who are your firm's *clients* on residential projects? Please indicate the approximate proportion for each type.

A) Government projects [ ]%	B) Private Sector projects [ ]%
C) Semi-Government Projects [ ]%	D) Other, Specify _____________ [ ]%

16. How is your firm *engaged* to perform cost consultancy service?

A) As a part of the design package	B) As a separate package

17. Do you use any *specialized* cost estimating *software* in this firm? Please indicate the approximate proportion of projects for each option.

A) Yes [ ]%	B) No [ ]%

If your answer to 17 is No, go to Section B otherwise continue.

18. What is the name of the package
19. For how long have you been using the package _______ years
20. Who is the manufacturer
21. On a scale of 1 to 5, with 5 representing Very satisfied, how would you rate your satisfaction of the package

Section B: Early Cost Estimates and Design Variables

This section contains questions on early cost estimates for residential buildings and the procedures adopted by your firm in accounting for design variables in the early cost estimates prepared for residential buildings. Please answer the questions either by writing the required information in the space provided or by placing a tick (√) after the option that corresponds to your choice.

1. Do you prepare *early cost estimates for residential projects* in your firm?

A) Yes	B) No

2. Briefly describe the *estimating technique* you utilize in preparing early cost estimates for *residential projects* in your firm.

3. The following are *potential factors,* which may *impact* your decision for selecting the estimating technique to forecast the early cost of a residential building? You are kindly requested to indicate the level of effect by placing a tick (√) in the appropriate box.

	Factors	**Extremely important (4)**	**Very important (3)**	**Important (2)**	**Somewhat important (1)**	**Not important (0)**
A	Size of the project					
B	Client (owner)					
C	Project type					
D	Experience of estimator					
E	Information available					
F	Time available					
G	Construction method					
H	Design variables					
I	Expected number of bidders					
J	Others					

4	**Comparing the early cost estimates prepared in your firm with the eventual accepted tender price for projects previously undertaken by your firm, how would**

.	you ***rate the reliability*** **of the estimating technique utilized by your firm?**					
		Extremely reliable (4)	**Very reliable (3)**	**Reliable (2)**	**Somewhat reliable (1)**	**Not reliable (0)**
	In my opinion, it is					

The following are some of the *factors, which* may impact your decision on the following *design variables* of a residential building design? You are kindly requested to indicate the level of effect by placing a tick (√) in the appropriate box.

	Factors	**Extremely important (4)**	**Very important (3)**	**Important (2)**	**Somewhat important (1)**	**Not important (0)**
5. Plan shape						
A	Shape of the plot					
B	Functional requirements					
C	Intended use					
D	Others					
6. Total number of storeys						
A	Cost of land					
B	Prestige					
C	Planning laws					
D	Others					
7. Average storey height						
A	Intended use					
B	Environmental considerations					
C	Type of A/C system					

D	Others					
8. Amount of circulation space (entrance halls, corridors, stairways, lift wells)						
A	Expected traffic					
B	Safety (escape)					
C	Building codes					
D	Others					
9. Percentage of external wall area to be glazed						
A	Functional requirements					
B	Building codes					
C	Owner's wish					
D	Others					
10. Mechanical and Electrical (M&E) services						
A	Percentage of glazed wall area					
B	Perimeter length					
C	Total building height					
D	Volume of plant rooms					
E	Total enclosed volume					
F	Total floor area					

G	Building services codes					
H	Intended use					
I	Others					
11. How important do you consider the application of "*Constructability/Buildability*" as a design tool?						
	In my opinion, it is					

12. What is the average percentage of the total floor area that you provide as *circulation space* in your residential building designs?
__________________%

13. What is the average percentage of the total external wall area that you provide as *glazed area* in your residential building designs?
__________________%

14. What is the average percentage of the total cost that is represented by *M&E services* for a residential building design?
__________________%

15. Are there any specific *systematic procedures* adopted by your firm for accounting for design variables in the early cost estimates prepared for residential building projects, and during early cost advice to your clients?

A) Yes	B) No

If your answer to 15 is No, please go to 23, otherwise continue.

Provided below are some of the procedures used in accounting for design variables while forecasting the cost estimates of a residential building during the early design phase. You are kindly requested to indicate how you account for each of the design variables either by placing a tick (√) after the appropriate option or by providing a brief description in the space provided.

16. Plan shape

A) Established plan shape indices	B) Wall/Floor ratio
C) None of the above, but it is done as described below:	

17. Number of storeys

A) By detailed analysis	B) Simple ratio
C) Cost model developed by this firm	D) Optimum number of storey formula
E) None of the above, but it is done as described below:	

18. Average storey height

A) By detailed analysis	B) simple ratio
C) Cost models developed by researchers	D) Cost models developed by this firm
E) None of the above, but it is done as described below:	

19. Circulation space

A) By detailed analysis	B) Simple ratio
C) Cost model developed by this firm	D) Cost models developed by researchers
E) None of the above, but it is done as described below:	

20. Window (glazed) area

A) By detailed analysis	B) Simple ratio
C) Cost model developed by this firm	D) Optimum number of storey formula

F) None of the above, but it is done as described below:

21. Mechanical & Electrical engineering services

A) By detailed analysis	B) Simple ratio
C) Cost models developed by researchers	D) Cost models developed by this firm
E) None of the above, but it is done as described below:	

22. Density of internal partition

A) By detailed analysis	B) Simple ratio
C) Cost model developed by this firm	D) Cost models developed by researchers
F) None of the above, but it is done as described below:	

	Outcome	Extremely severe (4)	Very severe (3)	severe (2)	Somewhat severe (1)	Not severe (0)
23.	**The following are some of the *consequences of under-assessing* the cost implication of design variables in the early cost estimates prepared for residential building projects. You are kindly requested to indicate the degree of severity for each factor by placing a tick (√) in the appropriate box.**					
A	Recommendation of infeasible project					
B	Eventual abandonment					
C	Disappointing expected returns					
D	Substandard quality of work					
E	Others					

24.	**The following are some of the *consequences of over-assessing* the cost implication of design variables in the early cost estimates prepared for residential building projects. You are kindly requested to indicate the degree of severity for each factor by placing a tick (√) in the appropriate box.**					
A	Loss of owner's confidence					
B	Rejection of feasible project					
C	Lost opportunities					
D	Others					
25.	**How important is the application of *systematic procedure* in accounting design variables?**					
	In my opinion, it is					

	Factors	**Extremely reliable (4)**	**Very reliable (3)**	**Reliable (2)**	**Somewhat reliable (1)**	**Not reliable (0)**
26.	**How would you *rate the procedures* adopted by your firm in accounting for the cost implication of design variables in early cost estimates prepared for residential building projects?**					
	In my opinion, it is					

27. Please provide *additional comment* on how to improve the accuracy of early cost estimates prepared for residential building projects.

APPENDIX B

PRELIMINARY PROJECT DESCRIPTIONS

GENERAL: Building size – 15m x 20m, 2 floors, 1.2m high parapet wall, bay size 5m x 5m, ceiling heights are 3m, 750m^2 lot size.

A10 FOUNDATIONS – Normal soil conditions; Isolated footing of 3500psi concrete, normal steel, sawn timber formwork; Imported earth backfill; 3500psi concrete grade beams, normal steel, sawn timber formwork; 2500psi concrete slab on grade, 20cmx20cm uncoated wire-mesh steel, sawn formwork.

B10 SUPERSTRUCTURE – 30m Hordi slab system; 3500psi concrete roof deck, normal steel, sawn timber formwork; 4000psi concrete columns, uncoated normal steel, sawn timber formwork; 4000psi concrete beams, uncoated normal steel, sawn timber formwork.

B20 EXTERIOR CLOSURE – 20cm Insulated blocks, 10% windows – 6mm thick double-glazed, 7 % doors – Steel and Wooden.

B30 ROOFING – 4 ply Tar and gravel, 5cm rigid insulation

C10 INTERIOR CONSTRUCTION – 20cmx20x40cm CMU Hollow concrete block partitions, 10% doors – wooden.

C20 STAIRCASES – 3500psi regular concrete stairs, uncoated normal steel, sawn timber formwork

C30 INTERIOR FINISHES – Wall finishes: Plaster and Painting to ceiling height. Floor finishes: 20% marble in circulation spaces, 80% screed only. Ceiling finishes: Plaster and Painting.

D20 PLUMBING – Plumbing fixtures, Domestic water distribution, Sanitary wastes, Rain water drainage.

D30 HVAC – Split air-conditioning system

D40 FIRE PROTECTION – Standard sprinkler system.

D60 ELECTRICAL – Service, 300 Amp with 3 panel boards and feeder. Lighting, fire protection systems, smoke and heat detectors.

APPENDIX C

DRAWINGS

APPENDIX D

APPENDIX E

LIST OF CONSULTANTS

The following is the list of consultants in the Eastern Province:

S/#	Name of Consultant	Address	Phone	Fax.
01	Abdulaziz Al-Othman & Partners Engineering Consultancy.	P.O. Box # 1445, Khobar, 31952.	8944563	8944578
02	Abdullah Al-Moaibed Engineering Office	P. O Box # 61, Dhahran 31932.	8951400	8647965
03	Abdullah Al-Juaib Engineering Office	P. O Box # 9437, Dammam 31413.	8421492	8428360
04	Abdulrahman Al-Shaikh Mubarak Office	P. O Box # 1673, Dhahran 31952.	8951802	8946573
05	Abdulrehman Mohammad Al-Shuhail Engineering Consultants	P. O Box # 6047, Dammam 31442.	8330108	8340607
06	Al-Dammam Engineering Center	P. O Box # 4195, Dammam 31491.	8333700	8340398
07	Al-Dossary Engineering Office	P. O Box # 4024, Dhahran 31491.		
08	Adnan Bassam Office	P. O Box # 24, AL-Khobar 31952.	8980071	8993282
09	Ahmed Al-Mousa Engineering Consultant	P. O Box # 7266, Dammam 31462.	8348883	8343944
10	Ahmed Omar Radi Architect	P. O Box # 1841, Dammam 31441.	8338544	8338538
11	Ahsan Al-Abbab Engineering Office	P. O Box #30489 Khobar 31952.	8991288	8648917
12	Aiman Malaikah Engineering and Topography Consultaning Office	P. O Box # 3472, Khobar 31952.	8941069	8649937
13	Al-Ahmadi Consulting Engineer	P. O Box # 724 Jubail 31961.	3613736	3615150
14	Al-Amir Office for Engineering Studies.	P. O Box # 5177, Dammam 31422.	8349478	
15	Al-Buraiki Engineering Office	P. O Box # 234, Qateef 31911.	8553309	8553321
16	Al-Dahli Engineering Services	P. O Box # 3685, Dammam 31481.	8322121	8330260
17	Al-Fawzan Engineering Office	P. O Box # 3908, Khobar 31952.	8649297	8952148
18	Al-Ghannam Engineering Office.	P. O Box # 716, Jubail 31951.	3611994	3611498
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21	Al-Hamdan Consulting Office	P. O Box # 2474, Khobar 31952.	8983641	8946872

22	Al-Hamed Technical and Engineering Services.	P. O Box # 6022, Dammam 31442.	8267495	
23	Al-Hassan Engineering Consultancy.	P. O Box # 8943, Dammam 31492.	8345059	8343623
24	Al-Hoty - Stanger Limited	P. O Box # 1122, Khobar 31852.	8980958	8981466
25	Al-Ibrahim Engineering and Surveying Office	P. O Box # 10153 Awamia 31911.	8520948	8520948
26	Al-Ibrhim Engineering Office	P. O Box # 5091, Khobar 31422.	8331259	
27	Al-Id Engineering Consultants	P. O Box # 5967, Dammam 31432.	8332266	8324341
28	Al-Khobar Engineering and Consulting Center.	P. O Box # 888 AL-Khobar 31952.	8577778	8577906
29	Al-Mald Engineering Office	P. O Box 426, Hafr Al-Batin 31911.	7221836	
30	Al-Maldh Engineering Consultancy	P. O Box # 3278, Dammam 31471.	8335170	8336009
31	Al-Marhoon Engineering and Consulting Office	P. O Box # 1934, Dammam 31441.	8422320	
32	Al-Momin Engineering Office	P. O Box # 2309, Khobar 31952.		
33	Al-Mustafa Engineering Office	P. O Box # 407, Qateef 31911.	8559523	8559515
34	Al-Nafea Engineering Office	P. O Box # 550, Khobar 31952.	8945321	8952936
35	Al-Obaidli Architectural and Design Office	P. O Box # 5816, Dammam 31432.	8336000	8575647
36	Al-Ojairi Designing Center	P. O Box # 9827, Dammam 31423.	8333305	8326047
37	Al-Osaimi Engineering Office	P. O Box # 1736, Khobar 31952.	8573668	8573144
38	Al-Othman Center for Architectural and Engineering Design.	P. O Box # 518, Dammam 31421.	8951818	8640758
39	Al-Othman Consultants	P. O Box # 30052 Khobar 31952.	8951717	8640758
40	Al-Qatari Consultants	P. O Box # 570, Qateef 31911	8540961	8540641
41	Al-Rabdi and Al-Baldali Engineering Consultancy and Services	P. O Box # 4138, Khobar 31952	8990095	8993430
42	Al-Rabdi Engineering Consultancy	P. O Box # 4138, Khobar 31952	8992202	8993430

43	Al-Royah Architectural Design Office	P. O Box # 4018, Khobar 31952	8944936	8987404
44	Al-Safi Engineering Office	P. O Box # 6790, Dammam 31542	8333302	8333302
45	Al-Sharq Engineering Office	P. O Box # 806, Khobar 31952	8983736	8945588
46	Al-Sindh Engineering Studies Office	P. O Box # 436, Khobar 31952	8644578	8644578
47	Al-Suhaimi Design Office	P. O Box # 161, Dammam 31411	8264243	8265343
48	Al-Sumait Engineering Services	P. O Box # 2736, Khobar 31952	8575714	
49	Al-Owaid Engineering Office	P. O Box # 30164 Khobar 31952	8985619	8945841
50	Al-Wakeel Engineering Office	P. O Box # 30285 Khobar 31952	8940093	8946961
51	Al-Yousuf Civil Engineering Office	P. O Box # 4519, Dammam 31412	8428450	8425180
52	Al-Zarki for Civil Engineering	P. O Box # 2203, Dammam 31451	8272675	8262471
53	Al-Zawad Engineering Office	P. O Box # 5430, Dammam 31422	8422348	
54	Al-Awami Planers and Consultants	P. O Box # 88, Qateef 31911	8551006	8553768
55	Ali Khudair Al-Harbi and Ahmad Omar Radhi Engineering Consultancy	P. O Box # 684, Khobar 31952	8951777	8942122
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57	Arabesque Consulting Engineers	P. O Box # 3513, Khobar 31952	8940320	8950452
58	Arabian Consulting Engineering Center	P. O Box # 3790, Khobar 31952	8595555	8574317
59	Arabian Geophysical and Surveying Company (ARCAS)	P. O Box # 535, Khobar 31952	8577472	8579042
60	Architectural and Engineering Services Technical Office	P. O Box # 1178, Dammam 314312	8266125	8266684
61	ASAS for Engineering Designs and Technical Enterprises	P. O Box # 6579, Dammam 31452	8271922	8269589
62	Ayadh Al-Fadhli Engineering Office	P. O Box # 1306, Khobar 31952	8945588	8945588
63	Ba-Al Haddad Engineering Office	P. O Box # 21, Khobar 31952	8642186	
64	Bakr Al-Haajri for Architectural Engineering	P. O Box # 2455, Khobar 31952	8982990	8985255

65	Bu-Kannan Engineering Office	P. O Box # 5378, Dammam 31422	8348701	8348591
66	Consulting and Design Engineering	P. O Box # 2502, Khobar 31952	8951832	8986312
67	Control Federal Systems Company	P. O Box # 888, Khobar 31952	8577910	8577906
68	Daka Surveying Saudi Arabia Limited	P. O Box # 4835, Dammam 31412	8262214	
69	Dar ul-Riyadh Consultants	P. O Box # 20753 Al-khobar 31952	8919584	8911656
70	Dar Al-Mustafa Civil Engineering	P. O Box # 100, Qateef 31911		
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95	Hassan Mehdi Al-Khaldaf Trading Services Establishment	P. O Box # 34632 Dammam 31478	8390226	
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129	Sooter, and Assam Abdulghani Engineering Consultancy	P. O Box # 3422, Dammam 31471	8268565	8276083
130	Suhail Yousif Al-Ali Architectural Engineering Office	P. O Box # 8544, Dammam 31492	8945370	8945370

131	Tamimi Engineering Office	P. O Box # 11006 Dammam 31451	8333222	8331005
132	Tariq Al-Yafi Engineering Consultancy	P. O Box # 9448, Dammam 31413	8346479	8346479
133	Tariq Hajj Architects	P. O Box # 64, Khobar 31952	8641844	8987163
134	Technical Engineering Office	P. O Box # 6858, Dammam 31452	8345310	
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137	Western Geophysical Company	P. O Box # 1928, Khobar 31952	8640231	8643253
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REFERENCES

AbouRizk and Hajjar (1998). A framework for applying simulation in the construction industry, *Canadian Journal of Civil Engineering,* Ottawa, **25** (3)**,** 604-617.

Adrian, J.J. (1982). *Construction Estimating: an accounting and productivity approach*. Rexton Publishing Co. Inc. Virginia.

Adrian, J.J. (1981). *CM: The Construction Management Process*. Rexton Publishing Co. Inc. Virginia.

Aeroboe, M.B. (1995). Energy management strategies for facility managers. *SA Refrigeration and Air-conditioning,* **11** (1), 43-53.

Al-Asfoor, M.D. (1993). "Computerized Conceptual Cost-Estimating System for Domestic Water Supply Projects", unpublished thesis presented to King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia in partial fulfillment for the degree of Master of Science.

Ashworth, A. (1994). *Cost Studies of Buildings*. Longman, London.

Association for the Advancement of Cost Engineering (AACE) International (1992). *Skills & Knowledge of Cost Engineering,* AACE International, USA.

Barclay, J. (1994). "A comparison between traditional and non-traditional forms of contracting for the procurement of building projects", unpublished thesis presented to

School of Construction Management, Queensland University of Technology in partial fulfillment for the degree of Bachelor of Science.

Bojic, M., Yik, F., Wan, K. and Burnett, J. (2002). Influence of envelope and partition characteristics on the space cooling of high-rise residential buildings in Hong Kong, *Building and Environment,* **37** (4), 347-355.

Bowel, P. (1982). Problems in econometric cost modeling. *The Quantity Surveyor*.

Bozai, G.A. (1981). "Regression Analysis Models for Preliminary Cost Estimating in Highway Construction", unpublished thesis presented to NED University of Engineering and Technology, Pakistan in partial fulfillment for the degree of Master of Science.

Brandon, P.S. (1978). A framework for cost exploration and strategic cost planning in design, *Chartered Surveyor Building and Quantity Surveying Quarterly,* **5**(4)**,** 60-63.

Bubshait, A.A. and Al-Musaid, A.A. (1992). Owner Involvement in Construction Projects in Saudi Arabia, *J. of Management in Engineering,* **8**(2)**,** 176-185.

Carroll, D. (1982). Energy consumption and conservation in buildings: an international comparison. *Proceedings of the Third International Symposium on Energy Conservation in the Building Environment,* vol. 1A, CIB/An Foras Forbartha, Dublin, pp. 190-203.

CIRIA (1983). *Buildability: An Assessment.*

Chau, K.W. (1999). On the issue of plan shape complexity: plan shape indices revisited, *Construction Management Economics,* **17,** 473-482.

Cheong, P.E. (1991). "Accuracy of design stage cost estimating", unpublished thesis presented to National University of Singapore in partial fulfillment for the degree of Master of Science.

Clark, W. and Kingston, J. (1930). *The Skyscraper: A Study in the Economic Height of Modern Office Buildings*. American Institute of Steel Construction, New York.

Clough, R.H. and Sears, G.A. (1994). *Construction Contracting*. John Wiley & Sons Inc. New York.

Collier, K. (1987). *Fundamentals of Constructing Estimating and Cost Accounting.* Prentice Hall, Englewood Cliffs, N.J.

Daschbach, J.M. and Agpar, H. (1988). Design analysis through techniques of parametric cost estimation, *Engineering costs and Production Economics,* **14**, 87-93.

Diekmann, J.E. and Girard, M.J. (1995). Are contracts disputes predictable?, *J. of Construction Engineering and Management,* **121** (4), 355-363.

DeGoff, R.A. and Freidman, H.A. (1985). *Construction Management: Basic principles for architects, engineers and owners*. John Wiley & Sons Inc. New York.

Dell'Isola, A. (1997). *Value Engineering: Practical Applications*. RS Means CMD Group, USA.

Department of the Environment (1971). *Local Authority Offices: Areas and Costs*. DOE, London.

Eldeen, T.A.M.S. (1996). "Budget Estimating Models for the Construction Cost of Public School Buildings in Saudi Arabia", unpublished thesis presented to King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia in partial fulfillment for the degree of Master of Science.

Ellis, M.W. (1996). “Practical evaluation and integrated simulation of building HVAC system performance”, unpublished thesis presented to University of Pretoria in partial fulfillment for the degree of Master of Science.

Ferry, D. and Brandon, P. (1991). *Cost Planning of Buildings*. Granada, London.

Gunner, J. and Skitmore, M. (1999). Comparative analysis of pre-bid forecasting of building prices based on Singapore data, *Construction Management and Economics,* **17**, 635-646.

Halpin, D.W. (1977). CYCLONE – Method for modeling job site processes, *J. of Construction Division,* ASCE, **103** (3)**,** 489-499.

Hillebrandt, P.M. (1985). *Economic theory and the construction industry (2nd edn.).* Macmillan Press Ltd., London.

Horner, M. and Zakieh, R. (1996). Characteristic items – a new approach to pricing and controlling construction projects, *Construction Management Economics,* **14,** 241-252.

Kish, L. (1995). *Survey Sampling*, John Wiley and Sons Inc., New York.

Kosonen, R., and Shemeika, J. (1997). The use of a simple simulation tool for energy analysis. *Proceedings of the Fifth International IBPSA Conference,* Prague, Czech Republic, vol. 2, pp. 369-376.

Kouskoulas, V. and Koehn, E. (1974). Predesign Cost-Estimation Function for Buildings, *Journal of the Construction Division ASCE*, **100**(12), 589-604.

Ling, Y.Y. (2002). Model for predicting performance of Architects and Engineers, *J. of Construction Engineering and Management,* **128** (5), 446-455.

Ling, Y.Y. and Boo, J.H.S. (2001). Improving the accuracy of approximate estimates of building projects, *Building Research and Information,* **29** (4), 312-318.

Molenaar, K.R. and Songer, A.D. (1998). Model for public sector design-build project selection, *J. of Construction Engineering and Management,* **124** (6), 467-479.

Al-Momani, A.H. (1996). Construction cost prediction for public school buildings in Jordan, *Construction Management Economics,* **14,** 311-317.

Moore, P. (1988). Working along the right lines, *Chartered Quantity Surveyor,* October.

Oberlender, G.D. and Trost, S.M. (2001). Predicting accuracy of early cost estimates based on estimate quality. *J. of Constr. Engrg. and Mgt.,* ASCE, **127** (3), 173 – 182.

Ogunlana, S.O. (1989). "Accuracy in Design Cost Estimating", unpublished doctoral thesis submitted in partial fulfillment of the requirements for the award of Doctor of Philosophy of the Loughborough University of Technology.

Pristker, A.A.B. (1986). *Introduction to Simulation and SLAM-II*, Wiley, New York.

Raddon, P.S.B. (1982). *Building Cost Techniques*, E. and F.N. Spon, London.

Ranasinghe, M. (1996). Total project cost: a simplified model for decision makers, *Construction Management Economics,* **14,** 497-505.

Rowe, K.R. (1975). *Management techniques for Civil Engineering Construction*. Applied Science Publishers, London.

Russell, J.S. and Jaselskis, E.J. (1992). Quantitative study of contractor evaluation programs and their impact, *J. of Construction Engineering and Management,* **118** (3), 612-624.

Schueller, W. (1986). *High-rise Building Structures*. Robert Krieger, Malabar.

Seeley, I.H. (1996). *Building Economics*. Macmillan, London.

Shash, A. and Al-Mulla, E. (2002). Major components of "Typical Villa" in Saudi Arabia for price/cost index development. *Proceedings of the Sixth Saudi Engineering Conference,* Vol. 1, KFUPM, Dhahran, December 2002, pp. 47-62.

Smith, N.J. (1995). *Project cost estimating*. Thomas Telford, London.

Stone, P. (1963). *Housing, Town Development Land, and Costs*. Estates Gazette, London.

Swaffield, L.M. and Pasquire, C.L. (1995). A critical analysis of building services cost prediction models, in *ARCOM Eleventh Annual Conference,* September 1995, pp. 424-433.

Swaffield, L.M. and Pasquire, C.L. (1996). A critique of mechanical and electrical services cost planning: existing methods and published information, *Journal of Financial Management of Property and Construction,* **1**(3)**,** 23-41.

Swaffield, L.M. and Pasquire, C.L. (1999). Examination of relationships between building form and function, and the cost of mechanical and electrical services, *Construction Management Economics,* **17,** 483-492.

Swinburne, H. (1980). *Design cost analysis*. McGraw-Hill Book Co., New York.

Tan, W. (1999). Construction cost and building height, *Construction Management Economics,* **17,** 129-132.

Thomsen, C. (1966). How high to rise. *Appraisal Journal,* **34**(4), 585-91.

Al-Thunaian, S.A. (1996). “Cost estimation practice for buildings by A/E firms in the Eastern province, Saudi Arabia”, unpublished thesis presented to King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia in partial fulfillment for the degree of Master of Science.

Tregenza, P. (1972). Association between building height and cost, *Architects Journal,* November, 1031-2.

Turner, G.R. (1986). *Construction Economics and Building Design: A Historical Approach.* Van Nostrand Reinhold Company, New York.

Waier, P.R. and Linde, C.W. (1993). *Means Unit Price Estimating methods: Standard Procedures for using Unit Price Cost data*. R.S. Means Co. Inc.

Wilderness Cost of Building Study Group (1964). “An investigation into building cost relationships of the following design variables: storey heights, floor loadings, column spacings, number of storeys”, RICS.

Williams, T.P. (2002). Predicting completed cost using bidding data, *Construction Management Economics,* **20,** 225-235.

VITA

Ahmed Doko Ibrahim was born in the Doko town, Nigeria on September 14, 1974. Mr. Ibrahim joined Ahmadu Bello University, Zaria in 1992 and obtained a Bachelor of Science (Honors) degree in Quantity Surveying in 1998. After graduation, he served for one year with Ahmadu and Partners, a Quantity Surveying Consultancy firm, providing professional services on various private and public sector construction projects. He then joined Ahmadu Bello University, Zaria as an Assistant Lecturer in the Department of Surveying since April 2000, where he was working until he joined King Fahd University of Petroleum & Minerals as a Research Assistant in September 2001. Mr. Ibrahim is an active member of both AACE International and the Project Management Institute.

Cost Implications of Architectural Design Variables

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This thesis, written by **AHMED DOKO IBRAHIM** under the direction of his Thesis Committee, and approved by all the members, has been presented to and accepted by the Dean, College of Graduate Studies, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN CONSTRUCTION ENGINEERING & MANAGEMENT.**

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DEDICATION

In the Name of Allah, the most Gracious, the most Merciful.

“So verily, with every difficulty, there is relief. Verily, with every difficulty, there is relief. Therefore, when you are free from your immediate task, still labor hard (for another). And to your lord, turn (all) your attention” Qur’an 94: 5-8.

“ This thesis is dedicated to the memory of my late beloved father (May Allah grant him eternal rest, Aameen), and to my affectionate mother"

ACKNOWLEDGMENT

I am grateful to Allah for His guidance and protection throughout the course of this study, and for making the study a reality.

Acknowledgement is due to King Fahd University of Petroleum & Minerals for support of this research.

I wish to express my appreciation to Professor Ali A. Shash who served as my major advisor and for his time and interest in providing any needed direction, in spite of his tight schedules, throughout the course of the study. I also wish to thank the other members of my thesis committee, Prof. Sadi Assaf and Prof. Osama Jannadi for their valuable guidance and co-operation in completing this work. I am particularly indebted to Prof. Assaf for the academic and research induction provided throughout the course of my study.

I am also grateful to the firms that participated in the survey and the ones that provided other forms of data. Their efforts were very valuable to the successful completion of this study.

I would also like to extend my gratitude to the Chairman, all the Professors and the Secretary of the Construction Engineering & Management Department for all the support granted to me throughout my program. I am equally grateful for the friendly interaction with the other colleagues in the department. I also wish to extend my appreciation to the entire Nigerian community in and around KFUPM for all the moral support and for the homely treatment that I received throughout the course of my program.

I am most indebted to all my brothers, especially Dr. H.D. Ibrahim and Muhammad A. Yanda & their families, and to all my sisters for their special encouragement, prayers and moral support. I am equally grateful for the understanding, patience and prayers provided by Farida and her family. I pray that Allah reward you all abundantly.

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MAJOR FIELD : CONSTRUCTION ENGINEERING & MANAGEMENT

DATE OF DEGREE : JUNE 2003

The target of this research is to assist designers in understanding the cost implication of design variables, so that they can make more objective design decisions and offer more objective cost advice for the benefits of their clients. This research was focused to achieve two major targets. After thorough review of relevant literature in order to gain insight into the research theme, the first target was to investigate the procedures adopted by A/E firms in accounting for design variables in the early cost estimates they prepare for residential buildings. This was achieved through the administration of questionnaire. Nineteen (19) firms working in the Eastern province of Saudi Arabia participated in the survey. The survey results revealed that most of the A/E firms do not utilize specialized software packages in carrying out cost estimating services. Also, the firms neither utilize any systematic procedures in accounting for design variables nor the models developed by construction researchers. The second target was concerned with the empirical study of the effects of architectural design variables on the cost of residential building in a series of simulation experiments. The design variables that were studied include Plan shape, Size, Average storey height, and number of storeys. An empirical cost-estimate model of a "typical Saudi Arabian villa" was prepared and used for the simulation. The effects of the other factors on construction cost were held constant during the simulation runs and conclusions to a number of hypotheses formulated, among other things, were sought from the results of the simulation runs.

Similar studies have been recommended for other project types (such as Industrial and Commercial buildings), and on Design-Build contractors and estimating personnel working in relevant Government agencies.

خلاصة الأطروحة

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عنوان الدراسة: **تأثير التغيير في عناصر التصميم الهندسي على التكاليف**

حقل الاختصاص: **هندسة وإدارة التشييد**

تاريخ الدرجة: **ربيع الآخر 1424هـ**

إن الغرض من هذا البحث هو مساعدة مصممي الأبنية على فهم تأثير التغيير في عناصر التصميم الهندسي على تكاليف هذه الأبنية. وهذا مما يمكنهم من اتخاذ قراراتهم بأكثر موضوعية، وكذلك تقديم مشورة أكثر موضوعية لعملائهم بالنسبة للتكاليف التي سيتحملونها. وقد تركز البحث حول تنفيذ مهمتين أساسيتين. تناولت المهمة الأولى، بعد القيام بدراسة دقيقة للمراجع المناسبة لتكوين فهم لموضوع البحث، استقصاء الطرق التي تستخدمها المؤسسات الهندسية لتأخذ بعين الاعتبار تأثير التغيير في عناصر التصميم على حسابات التكلفة المسبقة التي تقوم بها بالنسبة للأبنية السكنية. وقد تم تنفيذ هذه المهمة بإجراء استبيان اشتركت فيه تسع عشرة (19) مؤسسة عاملة في المنطقة الشرقية من المملكة العربية السعودية. وقد أظهرت نتائج الاستبيان أن أكثر المؤسسات لا تستخدم برامج حاسوبية متخصصة في عملية تقدير تكلفة خدماتها. وبينت النتائج أيضاً أن هذه المؤسسات لا تستخدم أية طرق نموذجية لأخذ تأثير التغيير في عناصر التصميم بعين الاعتبار، ولا أية نماذج رياضية من تطوير باحثين في مجال البناء. أما المهمة الثانية، فقد عنيت بالدراسة الاختبارية لتأثير تغيير عناصر التصميم الهندسي على تكاليف الأبنية السكنية، وذلك بواسطة عمليات التمثيل التجريبي. وقد شملت عناصر التصميم التي تمت دراستها شكل المخطط، والحجم، ومعدل ارتفاع الطوابق، وعدد الطوابق. وجدير بالذكر أن نموذجاً رياضياً اختبارياً لتقدير تكلفة فيلا سعودية نموذجية قد أعد واستخدم في عمليات التمثيل التجريبي. وكان ذلك، على التوالي، بتغيير أحد عناصر التصميم وإبقاء العناصر الأخرى ثابتة، مما ساعد على الحصول على استنتاجات مفيدة بالنسبة لعدد من الافتراضات التي كانت موضع الاختبار.

وقد تمت التوصية أيضاً بتنفيذ مشاريع بحثية أخرى من نفس النوع (على الأبنية الصناعية والتجارية مثلاً) لتستخدم من قبل مقاولي التصميم والبناء والموظفين المخولين بتقدير التكاليف في الإدارات الحكومية المعنية.