DECISION ANALYSIS FOR HOUSNG-PROJECT DEVELOPMENT

By Mohamed M. Ziara[1] and Bilal M. Ayyub,[2] Fellow, ASCE

ABSTRACT: The implementation of an effective decision-making process for reducing the cost of housing can solve a significant part of the housing problems in countries with limited resources. Important cost-influencing factors are discussed in this paper, and general recommendations are outlined. One of the main objectives of this paper, however, is the development of a methodology based on decision analysis using a systems framework for effective uses of available resources. The methodology considers simultaneously the options and constraints of relevant socioeconomic factors in the planning and construction of urban housing-project developments. The methodology consists of the following steps: (1) Definition of possible scenarios for the use of resources; (2) assessment of the desirability of identified scenarios by potential residents; (3) assessment of the implementation suitability; (4) development of weight factors for desirability and implementation suitability of identified scenarios; and finally (5) decision analysis and selection of an optimal combination of scenarios. A case study example is used to demonstrate the practicality of the developed methodology for reducing the cost of houses.

INTRODUCTION

Countries with limited resources continually face housing challenges and limitations, especially in dealing with the impoverished segments of society. The lack of an appropriate national housing policy, the absence of a proper home-financing system, a primitive construction industry, and ineffective housing systems make housing unaffordable to people of limited income. It is believed that reducing the cost of houses can solve a significant part of housing problems all over the world. The implementation of an effective decision-making process for reducing the cost of housing can solve a significant part of housing problems under these conditions. Most recent research work on reducing the cost of houses has focused on individual influencing factors. The factors include new design methods and construction techniques (Handa and Oliveira 1993), use of unconventional and local building materials (Corson 1994; Falk 1994; Pinta and Agopyan 1994), use of specific regulations (Beaumont and Tippett 1993; Lagos and Handa 1993), more wise use of land (Coon 1997), use of special management and financial programs (Fear and Putt 1993; Knocke 1993; Hamdi 1997), etc. The cost of housing can be further reduced by utilizing decision theory in order to simultaneously and effectively use available resources and planning options.

One of the achieved objectives of this paper is the development of a methodology based on decision analysis using a systems framework for effective uses of available resources. The methodology considers simultaneously the options and constraints of cost-influencing factors in the planning and construction of housing-project developments. In comparison with rural housing developments, urban developments include a relatively large number of op-

---

[1]Asst. Prof., Dept. of Civ. Engrg., Birzeit Univ., Birzeit P.O. Box 14, Palestine (via Israel).

[2]Prof., Dept. of Civ. Engrg., Univ. of Maryland, College Park, MD 20742.

Note. Discussion open until November 1, 1999. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on September 25, 1997. This paper is part of the ***Journal of Urban Planning and Development***, Vol. 125, No. 2, June, 1999. ©ASCE, ISSN 0733-9488/99/0002-0068–0085/$8.00 + $.50 per page. Paper No. 16675.

tions and constraints related to each of the cost-influencing factors. Therefore the methodology is most suitable for implementation in urban housing developments since it can handle the large number of options and constraints related to the cost-influencing factors. A decision maker in the housing sector (such as developer, authority, contractor, or consultant) can therefore implement the developed methodology and enable people of limited income to own homes taking into consideration political, physical, social, and economic constraints.

COST-INFLUENCING FACTORS

The implementation of the developed methodology requires the identification of various housing-cost influencing factors followed by the understanding of options and constraints related to these factors. In this section the most important cost-influencing factors are briefly discussed, and general recommendations related to these factors are outlined for the purpose of lowering the housing cost. The life-cycle cost for a housing unit can be said to consist of (1) initial cost, and (2) running costs. The initial cost includes primarily design and construction costs. The running costs include items such as energy costs, subdivision-maintenance costs, and the maintenance of both the exteriors and interiors of the housing-units (Knocke 1993). The initial cost of a housing unit consists of the costs of feasibility and development studies, design, unit construction, development of infrastructure, administration and sales, and financing. Some aspects of these costs are directly related to a unit, whereas others such as design and construction of utilities infrastructure are shared among several units within a project. Thus, the determination of the exact housing cost is a fiendishly difficult task, as the total cost is the cost of a sum of many smaller elements that change over time. In this study, the estimation of cost values of the different elements is used for comparison purposes only. Although absolute cost values would be different from one place to another, their relative values are expected to remain in the same range as estimated. Different geographical regions may have different circumstances; however, in this study the prevailing circumstances in countries of limited resources in the Middle East are considered, e.g., the Palestinian Territories (Mayo 1997).

Land

The cost of land represents one of the most important constraints encountered in selecting sites for low-cost houses. Normally, many options exist in selecting and utilizing housing sites for the purpose of lowering their costs (Coon 1997). Multistory buildings can be used in areas where the cost of land is very high. The shape of the built-up area with respect to the shape of land should be planned in order to maximize the use of land allowed by building regulations related to zoning. The use of centers of cities for the construction of low-cost houses may not be vital, considering the high cost of land. However, social problems may arise as a result of allocating separate areas for lower-income people, reducing diversity and integration of population. In order to minimize social problems and to create jobs for low-income people, mixed areas in which people from all income categories live should be developed. Selected areas for new housing developments should be of adequate condition for construction, and should have transportation and infrastructure accessibility. The supporting soil should be suitable in order to avoid additional costs that may arise as a result of using special foundation systems such as mat foundation or piles.

Building Materials

The high cost of building materials is another factor that results in reducing housing affordability for low-income groups. Building materials may represent about 40% of the total construction costs for a house in developing countries in the Middle East (Hakmeh 1996). The effective use of building materials would help to reduce building costs and improve affordability to people. Many cost-reduction options of building materials exist that can be considered by planners and developers. They include the use of local materials more economically and the increasing of their structural efficiency. Also, significant improvements in efficient use of conventional materials such as reinforced concrete can be made. For example, it was shown (Ziara et al. 1995) that the use of overreinforced beams, which are not allowed by the ACI code (ACI Committee 1995), could be beneficial and cost effective when confinement of concrete is present. The use of expensive finishing materials such as laminated wood, aluminum, and steel should be minimized in the production of low-cost housing. Standard dimensions for doors, windows, and fittings would also contribute to lowering the total cost of buildings.

Labor

Labor-related constraints include the shortage of skilled and semiskilled construction workers, and the need to pay increased wages. This in turn may often contribute to a rise in the cost of housing units. Under such conditions the most economic form of construction is based on materials that can be fashioned without much skill and can be easily handled. This can be achieved by using semiindustrialized structural elements that could be erected by semiskilled labor with possible involvement of building owners, relatives, neighbors, and friends.

Infrastructure

Urban infrastructure provisions do not normally keep pace with population growth, industry demand, and demographic changes. Whether the infrastructure utility is related to transport, public roads, or housing, the role of the public sector is constrained in both policy and fiscal terms. The history of public subsidy in Middle Eastern countries to infrastructure has created an expectation that public works and services are inexpensive and freely available. The option of introducing realistic pricing mechanisms for infrastructure, applied to houses, will raise the cost of producing new housing and therefore raise housing prices (Hamdi 1997). This in turn will act as a boost to urban consolidation as the attraction of peripheral development is reduced. It is believed that to achieve sustainable housing development, there is a need to introduce the private sector in the provision and maintenance of infrastructure with respect to providing low-cost housing. The house prices will be in equilibrium with infrastructure costs only where there is full capital cost recovery and compensation for the cost of the advanced provision of infrastructure. In this case the increase in housing cost, as a result of infrastructure provision, approximately equals the value of the benefit they receive from the access to infrastructure. The adoption of the option of introducing a construction system of one model for buildings of more than one floor will result in the reduction of the cost of the infrastructure that serves several housing buildings.

Planning and Design

The need for planning cost control implies the availability of alternative methods of construction and use of materials. On the other hand, environmental and architectural needs impose serious constraints on planning freedom (Halliday 1994). The planning of a low-cost housing project should address available resources and their constraints. Planning and design should consider, among other factors, the use of land at regional and neighborhood levels, shape and size of buildings and housing units, and specifications of design details and construction elements. The most important cost-influencing factor to be considered in the planning of a housing unit is its size and shape. Normally, it is a cheaper option in two-story houses to place all sanitary appliances on the ground floor than to place them one over the other. Other options related to planning that would result in reducing the cost of houses are the increase in number of housing units served by the same staircase, foundation, and roof. Rectangular buildings are generally cheaper to build than other shapes. They lend themselves to the best ratio attainable between gross and net floor area. For buildings of less than three stories, the foundation system may consist of stemwall foundations for basement and crawl space homes (Overeem 1993). Flattened roofs cost less than roofs with other shapes (Stone 1976). Tall and narrow window openings are cheaper than other window forms. The option of using tall buildings increases the cost of a structure that may be required to resist increased levels of wind and earthquakes loads. For high-rise buildings, the cost of elevators and the cost of the lost time in lifting, materials, labor, and other items contribute to an increase in the total cost of a housing unit in the building. Standard element types are recommended for reducing the cost of housing, and are suitable for multistory residential buildings.

Regulations

The enforcement of building regulations constitutes an important set of constraints on the housing industry (McMurray and Cole 1959a). Regulations are more easily followed if all affected parties were participants in their development. Regulations, while allowing for the production of economical constructions, should ensure minimum standards with regard to structural safety, fire hazards, and public health, and should ensure human well-being in general (McMurray and Cole 1959b). Regulations should cover all aspects of building construction, such as planning and architectural criteria, building and design codes, land use and taxation, and construction safety.

Costs of Financing and Sales

The unavailability of relevant financial institutions constitutes an important constraint limiting the ability of people to own their own houses. The absence of special financing programs to serve the housing sector and the construction industry in general is a characteristic of the financial systems in developing countries in the Middle East (Mayo 1997). The options related to housing finance may include the introduction of regulations and a finance guarantee to encourage financing institutions to provide home mortgages. Subsidy programs must be designed to serve extremely poor people and social cases without causing distortion in the financing systems. The suitability of contract management, construction planning and cost control, and sale campaigns should be carefully studied in order to reduce the total cost of housing (McMurray and Cole 1959c).

GENERAL CRITERIA FOR REDUCING COST OF HOUSES

The implementation of the proposed methodology requires an effective use of available resources in relation to the factors that determine the cost of a housing project. For this purpose, the following general suggestions for the construction of low-cost housing projects are outlined based on the preceding discussions.

1. Generally permanent and environmentally sound buildings that require minimum maintenance should be produced. The houses should be protected from climate elements as much as possible. The housing projects should be aesthetically appealing to their potential occupants.
2. Local materials should be developed and used with minimum use of expensive imported building supplies.
3. Local semiskilled and unskilled workers, with minimum skilled supervision needed to ensure safety, should be utilized.
4. Housing designs should be flexible and suitable for open-ended construction systems that allow for modification and possible horizontal and vertical expansions to satisfy various needs of owners. Prefabricated construction components that are easy to make in small factories and can be transported easily and safely without breakage should be encouraged. The construction elements should be relatively simple to build, require minimum on-site preparation, and be able to be erected on rough grounds. Residential buildings should be planned, designed, and erected such that they utilize land, building materials, and supporting soil efficiently.
5. Final decisions regarding any housing-project development should be based on using the proposed methodology, which allows studying simultaneously all possible scenarios for using resources considering relevant cost-influencing factors and constraints.

COST-REDUCTION METHODOLOGY

The methodology consists of five main steps, outlined in Fig. 1. The figure also shows how the methodology accounts for interaction among relevant decision-influencing factors and potential outcomes. The five steps are described in the subsequent sections where a case study example has been developed to demonstrate the use and applicability of the proposed methodology. In the case study, the following three resource types were considered: (1) Land use; (2) offsite infrastructure; and (3) type of building.

Step 1: Definition of Scenarios for Resource Use

The identified resources, such as land use, offsite infrastructure and building type, and house-cost influencing factors are used in this step to develop all possible scenarios, as shown in Fig. 1. There is normally more than one option within each cost-influencing factor. Considering all possible combinations of options can result in a large number of *scenarios* related to all possible resource uses. To demonstrate the options for using resources, consider the land resource for a housing project that could be private, or public—it might be in the city center or on its periphery, it might be purchased or leased, etc. (Coon 1997). Therefore, the land resource could have eight options, as shown in Fig. 2. However, only three land use options, as shown in Fig. 3(a), were considered in the example to make it manageable.

A second resource example is infrastructure both in-site and off-site (Hamdi 1997). While the developer normally provides in-site infrastructure, the off-site infrastructure may or may not be available for the selected parcel

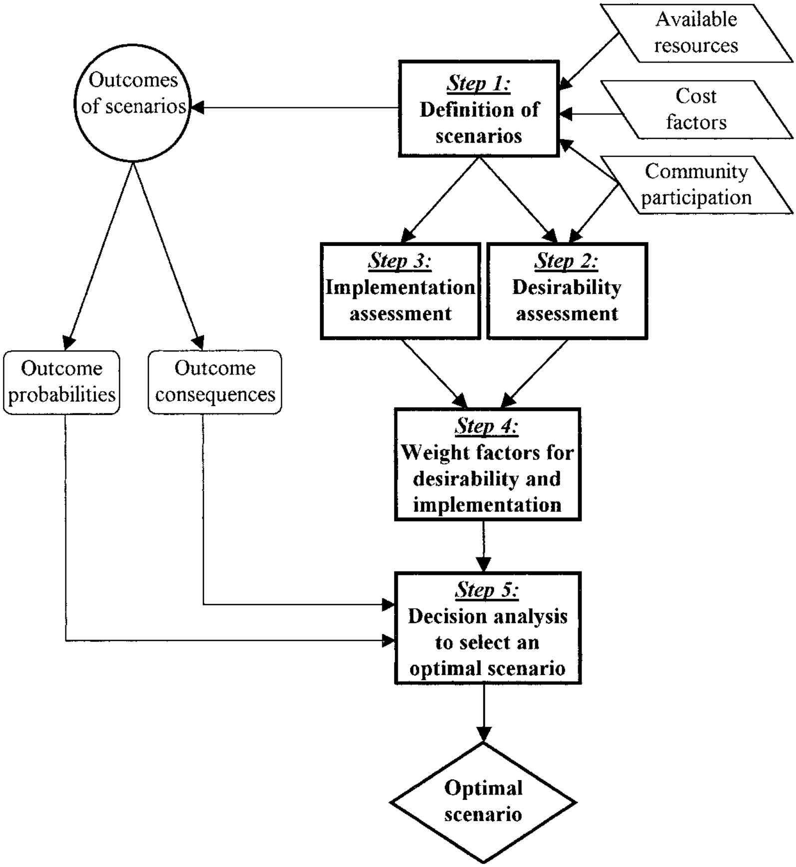

FIG. 1. Methodology for Cost Reduction

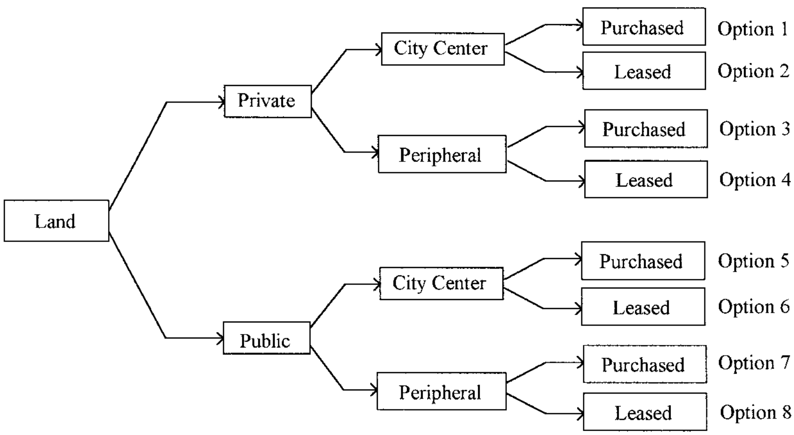

FIG. 2. Options of Land Use

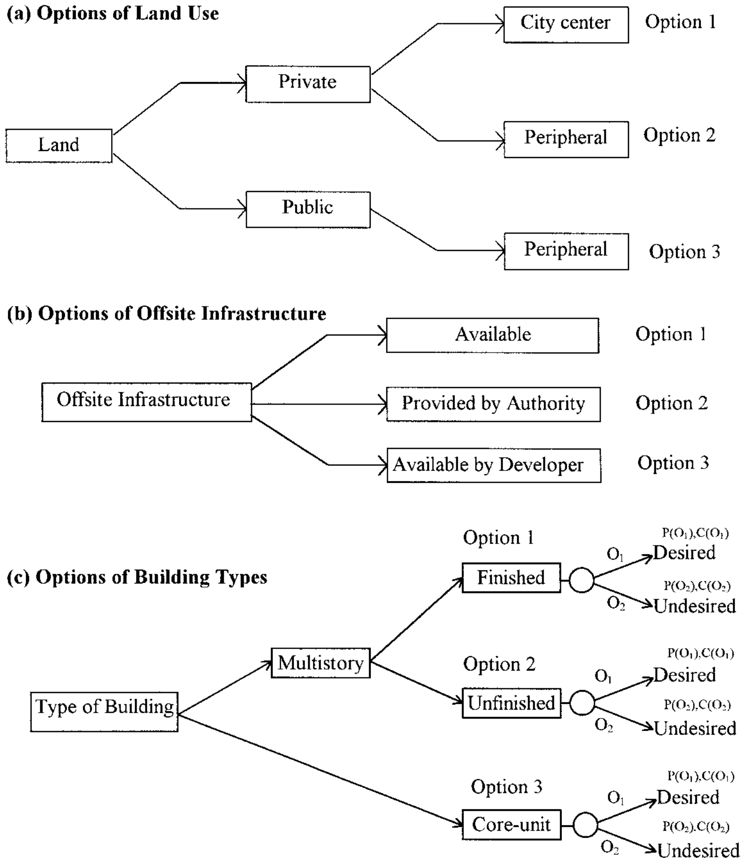

FIG. 3. Resource Options Used in Case Study Example

of land. If it is not, the development and construction cost of infrastructure might be paid by the developer or by the municipality or both. The off-site infrastructure resource that was considered in the example has three options, as shown in Fig. 3(b).

A third resource example is the type of building. The options could be high- or low-rise buildings. The buildings could be completely constructed or all skeleton structures. For the case of skeleton structures, the developer provides exterior and basic services, while finishing and fittings are not provided. Another option could be constructing core-unit houses in which only basic services and one or two rooms are provided, with possible future vertical or horizontal extensions left to the owner. The type of building resource that was considered in the example has three options, shown in Fig. 3(c). Other options for the type of building may include design and planning, structural systems, and finishing materials. Considering these options would result in additional scenarios related to the type of building. Options other than those shown in Fig. 3 could also exist, depending on prevailing circumstances. Consideration of all possible options related to land, infrastructure, and building type resources would result in a large number of possible scenarios. The following are only few scenarios that are identified based on these three resources:

Scenario 1: Purchasing a plot of private land in the city center where off-site infrastructure is available freely. Multistory buildings are constructed in which housing units are finished completely.

Scenario 2: Same as Scenario 1 except that the housing units are incomplete, i.e., skeleton buildings. In this case, the building is provided only with basic services such as water, electricity, sewer, and an elevator, while the units need internal partitions, finishing, fittings, and sanitary appliances.

Scenario 3: Same as Scenario 1 except that the core-unit houses are constructed, for which future vertical expansion can be made by respective owners. In this case the core units are completed, and provided with basic services.

Dealing with this problem in a nonsystematic manner as described above will become very difficult when considering other resources along with their possible options and constraints. Without using the developed methodology, the number of possible scenarios would become cumbersome to handle and prone to errors or omissions. The options based on an identified set of main resources can be included in a systematic manner as shown in Table 1, column 4, for the three resources considered in the case study (Fig. 3).

Step 2: Assessment of Desirability of Identified Scenarios

Decision-makers tend to emphasize economic factors more than social factors, traditional values, and desires of potential residents, in their investigation and/or development of housing projects. What is suitable and economically preferable to developers might not be desirable to residents. Worldwide experience includes many examples of unsuccessful housing projects that were

TABLE 1. Desirability and Implementation Suitability of Identified Scenarios

Resource				Desirability by Residents		Implementation Suitability	
Number (1)	Type (2)	Weight factor[a] (3)	Decision variables (4)	Desirability level[b] (5)	Weight factor[c] (6)	Suitability level[b] (7)	Weight factor[c] (8)
Resource 1	Land	0.4	Option 1	9	0.4	3	0.6
			Option 2	2		5	
			Option 3	7		7	
Resource 2	Off-site infra-structure	0.1	Option 1	10	0.3	9	0.7
			Option 2	5		6	
			Option 3	6		3	
Resource 3	Building type	0.5	Option 1	10	0.7	8	0.3
			Option 2	6		6	
			Option 3	6		5	

[a]Summation of weight factors for all resources = 1.
[b]Scale of 1 to 10; lowest level = 1 and highest level = 10.
[c]Summation of weight factors of desirability and suitability for source = 1.

planned, designed, and built by decision-makers, housing councils, or governments (Hamdi 1997). Learning from such unsuccessful experiences is important and can easily show that housing projects should be built with community participation, where the opinion of residents is considered at all stages of development. According to the developed methodology, community participation is a key element in making decisions, identifying possible scenarios, and selecting the most suitable scenario for a housing project, as shown in Fig. 1. The input of the community can be solicited and integrated toward a solution by assigning numbers on a scale of 1 to 10 based on the levels of desirability by residents for each identified scenario, as shown, for example, in Table 1, column 5. The one and ten values are assigned to the lowest and highest desirability levels, respectively.

Step 3: Assessment of Implementation Suitability

Scenarios vary in their implementation suitability. This step deals with the assessment of the implementation suitability and the effect of identified scenarios on housing units in terms of comfort, health and economy, the effect on infrastructure, and other concerns. The desires of residents that have been considered in Step 2 might not be affordable to them or economically preferable to developers. Thus, according to the proposed methodology, the suitability of identified scenarios for implementation is accounted for by decision-makers, as shown in Fig. 1. This step ensures that the most appropriate housing development scenario is not only desirable to residents but also practical for implementation. Suitability of identified scenarios for implementation is accounted for in the methodology by assigning numbers on a scale of 1 to 10 that correspond to the level of suitability (as shown, e.g., Table 1, column 7).

Step 4: Development of Weight Factors for Identified Scenarios

Weight factors for desirability and implementation suitability of identified scenarios are developed in this step as shown in Fig. 1. The identified scenarios are combinations of resources and cost-influencing factors that have various options. Normally, different resources have different importance levels. Moreover, the options of the resources do not all have the same importance. Similarly, desirability by residents and implementation suitability corresponding to each of the options has different levels of importance. In order to select the most suitable scenario, it is necessary to account for various levels of importance. The developed methodology accounts for the importance levels by assigning weight factors for the resources, desirability levels, and suitability levels [as shown, e.g., Table 1, columns (3), (6), and (8), respectively]. The weight factor ranges from 0.1 for the least important to 1 for the most important factor, with the constraint that weight factors for a given category must add up to one.

Step 5: Selection of Optimal Scenario Using Decision Analysis

Decision analysis is used in the final step of the methodology for the selection of an optimal combination of options by identifying the most suitable scenario. This step is considered very important because it allows decision makers to reach final selections regarding housing developments in a systemic manner despite the magnitude and complexity of the involved factors. Due to its importance, decision analysis as should be used in the methodology is described in some detail separately in the following section.

DECISION ANALYSIS

Engineering systems need to be defined in a well-structured, repeatable hierarchical form in order for one to perform consistent decision analysis. The definition of a hierarchy for housing units can be based on the objective of obtaining an optimal utilization of resources. Therefore, such a definition needs to include, among others, land, conceptual development and design, construction, finance, and sales. The development of a model for a system can be viewed as an abstraction of the system. The development of a model results in both introducing and defining uncertainties. Ayyub (1994) shows the type of uncertainties that often make model development difficult. Uncertainty in engineering systems can be mainly attributed to ambiguity and vagueness in defining the parameters of systems and their interrelationships. The ambiguity component is due to noncognitive sources, including physical randomness, statistical uncertainty due to the use of limited information to estimate the characteristics of these parameters, and model uncertainties that are due to simplifying assumptions. The vagueness-related uncertainty is due to cognitive sources such as definition of certain parameters, quality, deterioration, experience of people, human factors, and defining interrelationship of parameters. Ideally, the cost reduction of housing units should be based on life-cycle analysis. Depending on the type and availability of information, quantitative or qualitative analytical methods can be used (Gruhn 1991). Qualitative analysis uses expert opinion and judgment to obtain needed data or information. Quantitative analysis relies on test results, surveys, questionnaires, databases, and statistical methods for this purpose. It is common to use a combination of qualitative and quantitative methods in decision analysis. In the case study, qualitative measures of various factors are used.

The cost reduction of housing units requires a systematic evaluation and combination of various factors. Engineering decisions need to be made in a systems framework that considers all facets of a decision problem such that decisions may be analyzed and made, considering both uncertainties and socioeconomic factors. The decision framework is called the decision model. Decision analysis as presented herein (Ayyub and McCuen 1998) consists of the following five components that define the decision model:

<u>Decision Variables</u>. The first step in solving a decision problem is for the decision maker to identify a set of decision variables. The decision variables are the feasible alternatives (options) available to the decision maker at any stage of the decision-making process. Ranges of values that can be taken by the decision variables should be also defined. Decision variables can include a breakdown of land use, housing-unit type, infrastructure, and method of financing. Therefore, assigning a value to a decision variable means making a decision at a certain point in the decision-making process. These points within the decision-making process are called decision nodes. The decision nodes are identified in the model using a rectangle symbol (□). In the example, the decision nodes are the land use, the offsite infrastructure, and the type of building.

<u>Objectives of Decision Analysis</u>. This component of the decision model includes the formulation of an objective function that forms the basis to rank the desirability or suitability of the considered scenario in terms of the decision variables. Engineering decision problems can be classified into single- and multiple-objective problems. Examples of objectives are minimizing the total expected cost, maximizing safety, maximizing the total expected utility value, and maximizing the total expected profit. Decision analysis requires the definition of these objectives. Multiobjective decision analysis requires

measuring the objective in the same units. Therefore, weight factors can be used to combine these objectives. In the example, the developed methodology considers two objectives related to each option of the considered resources. The first objective is to maximize the desirability of the option by potential residents. The second objective is to maximize the implementation suitability of the option based on economical and technical considerations. These objectives are stated, respectively, in same units ranging from 1 to 10 in accordance with their importance levels, as shown in Table 1, columns 5 and 7. Different weight factors are also assigned to these objectives based on their relative importance, as shown in Table 1, columns 6 and 8, respectively. Consequently, the optimal scenario is obtained based on a weighted combination of the two objective functions.

Decision Outcomes. Due to the presence of uncertainties, the decision outcomes of the decision model need also to be defined. The decision outcomes are the events that can happen as a result of a decision. They are random in nature and their occurrence cannot be fully controlled by the decision maker. Decision outcomes can include, for example, land use that does not meet planned targets, and unplanned breakdown of the use of building types. Therefore, decision outcomes with the associated occurrence probabilities need to be defined. Decision outcomes occur after making a decision at points called chance nodes within the decision-making process. The chance nodes are identified in the model using the circle symbol ($\bigcirc$). The definition of decision outcomes is a difficult task; however, it can be viewed as a feedback to decision analysis within the proposed methodology. For simplicity, two decision outcomes are considered in the example for the building type option only, as shown in Fig. 3(c). These are the building types desired by the potential residents ($\bigcirc_1$) or not desired by the potential residents ($\bigcirc_2$).

Associated Probabilities and Consequence. The decision variables take values that can have associated costs. These costs can be considered as the direct consequences of making these decisions. The decision outcomes have both consequences and occurrence probabilities. The probabilities are needed due to the random, i.e., uncertain, nature of these outcomes. The consequences can include, for example, the building-type breakdown and the cost of deviations from planned land use. In the example, the occurrence probabilities $P(\bigcirc_1)$ and $P(\bigcirc_2)$, and the associated consequences $C(\bigcirc_1)$ and $C(\bigcirc_2)$ of the decision outcomes ($\bigcirc_1$) and ($\bigcirc_2$) related to building types, respectively, are shown in Fig. 3(c).

Decision Trees. The elements of a decision model need to be considered in a systematic form in order to make decisions that meet its objectives. Decision trees are commonly used to examine the available information for the purpose of decision making. The decision tree includes the decision and chance nodes. Decision nodes are followed by possible actions (or alternatives, A_i) that can be selected by a decision maker. Outcomes (or chances, $\bigcirc_j$) follow the chance nodes that can happen without the complete control of the decision maker. The actions have costs associated with them (CA_i), whereas the outcomes have both probabilities [$P(\bigcirc_j)$] and consequences ($C\bigcirc_j$). Each line followed from the beginning of the tree (left end) to the end of the tree (right end) is called a tree branch. Each branch represents a scenario of decisions and possible outcomes. For example, the total expected cost for each branch is computed. Then the most suitable decisions can be selected, such that the minimum total expected cost is obtained. In general, utility values can be used instead of cost values. Fig. 4 shows an example decision tree for the case study.

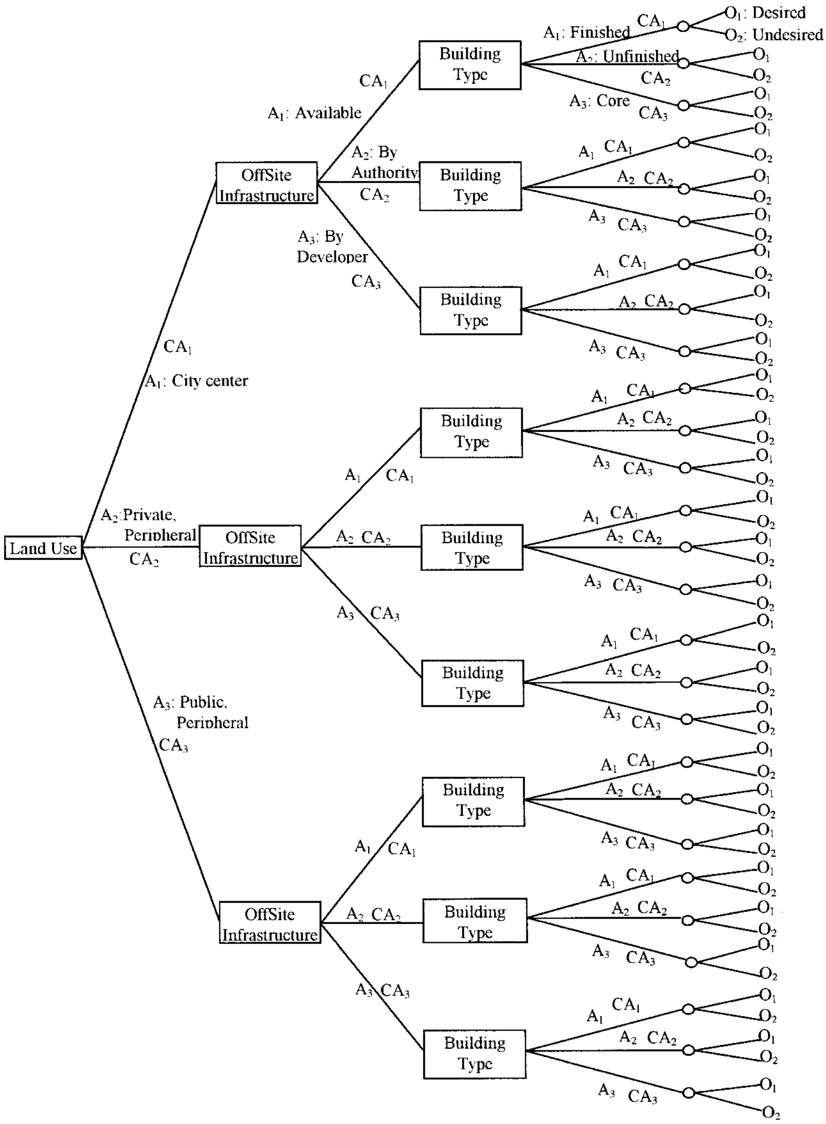

FIG. 4. Decision Tree for Case Study Example

INFORMATION NEEDS

The proposed methodology enables decision makers in the housing sector to select the most suitable solution for a housing project by dealing systematically with various options of resource use. It is implicitly assumed that all possible options for identified scenarios are known by decision makers. Moreover, the methodology requires the assignment importance values for desirability of residents and implementation suitability. In addition, weight factors for the decision variables are needed and should depend on their relative importance. These values may be obtained from parties involved in developing housing projects, including developers, decision makers, authorities, residents, experts, bankers, economists, and legislators. Past experience normally plays an important role in this process. Brainstorming sessions of involved parties can be used for acquiring required values. Although the required values cannot be obtained with a high level of accuracy, the accuracy of the methodology is partially dependent on the level of the relative accuracy of the used values. The insensitivity of the methodology to the absolute accuracy of these values makes it practical for use by decision makers with various level of expertise within the housing sector.

The cost of a housing project is believed to be the most important factor upon which the final decision regarding optimal combination of options scenario would be taken. Therefore, the figures assigned to importance levels and weight factors used in the methodology must be related to the cost of the scenarios. The methodology enables the selection of the most affordable housing projects. In the example, past experience and brainstorming sessions with experts (Ziara 1997) in the field of housing developments in the Middle East region have been utilized to solicit the required data. Data on levels of desirability by residents and implementation suitability were collected as shown in Table 1, columns 5 and 7, respectively. Corresponding weight factors for the decision variables, the desirability levels, and the implementation suitability levels were also selected, respectively, in the same manner as shown in Table 1, columns (3), (6), and (8). For example, the building-type variable can have values for the probabilities $P(\bigcirc_1)$ and $P(\bigcirc_2)$, and the associated consequences $(C\bigcirc_1)$ and $(C\bigcirc_2)$ for the two possible outcomes $(\bigcirc_1)$ and $(\bigcirc_2)$ that can be indicated on Fig. 3(c).

OPTIMAL SCENARIO

The case study example included three resources, i.e., the land use, the offsite infrastructure, and the building type. The decision variables are assumed to be three options per resource as shown in Fig. 3 and in Table 1, column 4. The required data for the decision variables are the corresponding weight factors and importance levels, as also shown in Table 1. In assigning these values, relative importance of decision variables was considered. For example, the weight factors for the land, the offsite infrastructure, and building type resources were 0.4, 0.1, and 0.5, respectively, as shown in Table 1, column 3. Thus, in this example the type of building is considered more important than the land use and off-site infrastructure. On the other hand, the weight factors for implementation suitability that correspond to the three resources were 0.6, 0.7, and 0.3, respectively, as shown in Table 1, column 8. Contrary to the relative importance of resources, the building type was considered in the example to be the least important (compared with the other two resources) based on implementation suitability. The combined objective function according to the methodology was based on the desirability by residents and implementation suitability for the decision variables. Consider, for example: The desirability levels related to land use as shown in Table 1, column 5 indicates that the option of using private land in the city center is most wanted by residents, with a desirability level of 9. Contrarily, the corresponding suitability level for the same option was equal to 3, indicating that using private land in the city center is less suitable because of its high cost for the housing project used in the case study. The corresponding weight factors for the desirability and implementation suitability for this resource were 0.4 and 0.6, respectively, as shown in Table 1, columns 6 and 8. This indicates that implementation suitability was considered to have more importance and greater influence on the final decision than the desirability by residents. On the other hand, the corresponding weight factors for the building-type resource for the example indicate that desirability by residents was considered to have more importance and greater influence than implementation suitability. Nevertheless, in the implementation of the developed methodology, different values can be assigned to the importance levels and weight factors, depending on relevant existing conditions and solicited data.

In the case study, the building-type decision variables can have two possible outcomes, as shown in Fig. 3(c). The corresponding probabilities and associated consequences that are required by the methodology for obtaining the optimal scenario are also shown in Fig. 3(c). It should be noted that the other two resources were considered not to have reasonable outcomes ($\bigcirc_j$) in order to simplify the example. The possible actions (A_i) related to all decision variables were considered to have associated cost (CA_i), as shown in the relevant decision tree for each resource. However, the costs were considered to be about the same for all actions, rendering them inconsequential in determining the optimal scenario.

The proposed methodology was used to obtain the optimal scenario based on the aforementioned data for the example. Table 2 shows the combination of the options comprising 27 scenarios without the consideration of the ran-

TABLE 2. Identified Scenarios

Scenario Definition		Combination of Resource Options			Scenario combined weighted rating
Number (1)	Code (2)	Resource 1 (3)	Resource 2 (4)	Resource 3 (5)	(6)
1	111	Option 1	Option 1	Option 1	7.79
2	112	Option 1	Option 1	Option 2	6.09
3	113	Option 1	Option 1	Option 3	5.94
4	121	Option 1	Option 2	Option 1	7.43
5	122	Option 1	Option 2	Option 2	5.73
6	123	Option 1	Option 2	Option 3	5.58
7	131	Option 1	Option 3	Option 1	7.25
8	132	Option 1	Option 3	Option 2	5.55
9	133	Option 1	Option 3	Option 3	5.4
10	211	Option 2	Option 1	Option 1	7.15
11	212	Option 2	Option 1	Option 2	5.45
12	213	Option 2	Option 1	Option 3	5.3
13	221	Option 2	Option 2	Option 1	6.79
14	222	Option 2	Option 2	Option 2	5.09
15	223	Option 2	Option 2	Option 3	4.94
16	231	Option 2	Option 3	Option 1	6.61
17	232	Option 2	Option 3	Option 2	4.91
18	233	Option 2	Option 3	Option 3	4.76
19	311	Option 3	Option 1	Option 1	8.43
20	312	Option 3	Option 1	Option 2	6.73
21	313	Option 3	Option 1	Option 3	6.58
22	321	Option 3	Option 2	Option 1	8.07
23	322	Option 3	Option 2	Option 2	6.37
24	323	Option 3	Option 2	Option 3	6.22
25	331	Option 3	Option 3	Option 1	7.89
26	332	Option 3	Option 3	Option 2	6.19
27	333	Option 3	Option 3	Option 3	6.04

dom outcomes for simplicity. If one would consider the two outcomes for only building type, there would be 54 combinations.

A combination that defines a scenario consists of three options. Each option corresponds to one of the available options for each of the three resources. The ratings and weight factors shown in Table 1 were combined to obtain a scenario's combined weighted rating (R_{ijk}) as follows:

$$R_{ijk} = 0.4(w_{Di}D_i + w_{Si}S_i) + 0.1(w_{Dj}D_j + w_{Sj}S_j) + 0.5(w_{Dk}D_k + w_{Sk}S_k) \quad (1)$$

where $i, j, k = 1, 2, 3$; w_{Di} = ith desirability weight factor; w_{Si} = ith suitability weight factor; D_i = ith desirability level or rating; and S_i = ith suitability level or rating. The numerical values of 0.4, 0.1, and 0.5 that appear in (1) correspond to the weight factors for the three resources used in the example. The computations are shown in Table 2, and indicate that the most suitable scenario is number 19, i.e., scenario code ijk = 311. The most suitable scenario states that ''finished housing units in multistory buildings should be constructed on public land on city periphery where offsite infrastructure is available.'' Parametric analysis was performed by slightly changing the weight factors, desirability levels, and suitability levels. The developed methodology is not sensitive to slight variations in these values. Outcomes from chance nodes in the decision tree that have probability distributions can be included in (1) by replacing the desirability values (D) or the suitability value (S) with their respective expected values $E(D)$ and $E(S)$ as follows:

$$E(D) = \sum_{p=1}^{n} D_p P(D_p) \quad (2a)$$

or

$$E(S) = \sum_{p=1}^{m} S_p P(S_p) \quad (2b)$$

where P = probability, and n and m = total number of chances for D and S, respectively. The variance can be computed using either first-order approximation based on Taylor series expansion, or Monte Carlo simulation (Ayyub and McCuen 1998). Adverse consequences can also be included in the model by expressing them using the same units of rating for D and S, and can be denoted as C_D and C_S, respectively, with associated probabilities $P(C_D)$ and $P(C_S)$, respectively. As a result, (1) can be revised as follows:

$$\begin{aligned} R_{ijk} = {} & 0.4\{w_{Di}[D_iP(D_i) - C_{Di}P(C_{Di})]\} + w_{Si}[S_iP(S_i) - C_{Si}P(C_{Si})] \\ & +0.1\{w_{Dj}[D_jP(D_j) - C_{Dj}P(C_{Dj})]\} + w_{Sj}[S_jP(S_j) - C_{Sj}P(C_{Sj})] \\ & + 0.5\{w_{Dk}[D_kP(D_k) - C_{Dk}P(C_{Dk})]\} + w_{Sk}[S_kP(S_k) - C_{Sk}P(C_{Sk})] \end{aligned} \quad (3)$$

Eq. (3) was reduced to (1) and used in the example by making the following substitutions: $P(D_i) = 1$; $P(D_j) = 1$; $P(D_k) = 1$; $P(C_{Di}) = 0$; $P(C_{Dj}) = 0$; and $P(C_{Dk}) = 0$.

SUMMARY AND CONCLUSIONS

The development and use of a cost-reduction methodology is described in this paper. The methodology consists of the following steps: (1) Definition of possible scenarios for the use of resources; (2) assessment of the desirability of identified scenarios by potential residents; (3) assessment of the implementation suitability and effect of identified cost-reduction scenarios on units, in terms of comfort, health, and other concerns, as well as the effect on infrastructure; (4) development of weight factors for desirability and implementation suitability of identified scenarios; and (5) decision analysis and selection of an optimal combination of options, i.e., scenario.

The proposed methodology is a universal tool in the sense of its applicability for urban housing projects intended to serve people of various income levels. However, its impact on the affordability of low- and middle-income groups can be most significant. A case study was used to demonstrate the practicality of the developed methodology for reducing the cost of houses. Based on this case study, the following conclusions can be drawn:

1. Reducing housing cost can significantly increase the ability of people to own houses. Significant reduction in cost of houses can be achieved by using a technique based on a criterion that considers all possible options for use of resources, while considering their constraints.
2. Decision-making for the selection of housing-project developments is difficult because decisions must be made under the uncertainty inherent in relevant socioeconomic factors. According to the methodology, decision analysis allows decision makers to make final selection regarding housing developments in a systemic manner despite system complexity and the magnitude of various significant cost-influencing factors.
3. Successful housing development can be achieved through decision-making with full community participation. In the developed methodology, the importance levels of the desirability of residents and implementation suitability of the options of the identified scenarios are accounted for in terms of values and weight factors.
4. The developed methodology is not sensitive to slight variations in values assigned to the levels of importance and their weight factors corresponding to different options.
5. The developed methodology has a practical value based on the case study that included 27 scenarios. In the case study, the methodology enabled the selection of the optimal combination of options identifying the scenario with the highest utility value.
6. General recommendations for reducing the cost of housing are provided in the paper, based on assessing various cost-influencing factors. Among these recommendations are the efficient use of local materials, controlling land cost in order to control the total cost of houses, the use of construction techniques that do not require skilled labor, the selection of proper shapes and configurations of buildings, and minimization of the impact of infrastructure on the total cost of houses.

ACKNOWLEDGMENTS

The writers acknowledge the financial support provided by the United Nations Development Fund through the TOKTEN program. This paper was based in part on this funding. Also, the writers would like to thank the final-year student Hekmat Abu-Hakmeh for his help in gathering some of the information presented in the paper.

APPENDIX. REFERENCES

Ayyub, B. M. (1994). ‘‘The nature of uncertainty in structural engineering.’’ *Uncertainty Modeling and Analysis: Theory and Applications*, B. M. Ayyub and Gupta, eds., North-Holland-Elsevier Science, New York.

Ayyub, B. M., and McCuen, R. (1998). *Probability, statistics and reliability for engineers*. CRC, Boca Raton, Fla.
Beaumont, P., and Tippett, H. (1993). ''Affordable housing through regulation: An evaluation of the performance based New Zealand building code.'' *Proc., 4th Annu. Rinker Int. Conf. on Build. Constr.*, College of Arch., University of Florida, Gainesville, Fla.
''Building code requirements for reinforced concrete, and commentary.'' (1995). *ACI 318-95/ACI 318R-95*, American Concrete Institute, Detroit.
Coon, A. (1997). ''Land and building use in relation to urban policies.'' *The Reconstruction of Palestine: Urban and Rural Development*, A. Zahlan, ed., Kegan Paul, London, 185–206.
Corson, J. N. (1994). ''Reuse of materials readily marketable with little or no processing.'' *Proc., 1st Int. Conf. of CIB TG 16*, C. J. Kibert, ed., Braun-Brumfield, Ann Arbor, Mich., 857–863.
Falk, R. H. (1994). ''Housing products from recycle wood.'' *Proc., 1st Int. Conf. of CIB TG 16*, C. J. Kibert, ed., Braun-Brumfield, Ann Arbor, Mich., 469–476.
Fear, J., Hutchinson, K., and Putt, T. (1993). ''Affordable future: Management of house procurement to optimize capital and maintenance costs.'' *Proc., 4th Annu. Rinker Int. Conf. on Build. Constr.*, University of Florida, Gainesville, Fla.
Gries, J. M., Ford, J., Wheeler, D. H., and Halbert, B. (1932). *Final report of the committee*, President's Conference on Home Building and Home Ownership, Washington, D.C.
Gruhn, P. (1991). ''The pros and cons of qualitative & quantitative analysis of safety systems.'' *Proc., Spring ISA '91 Sym.*, ISA, Edmonton, Canada.
Hakmeh, H. (1996). ''Introduction to low-cost housing.'' Graduation Project, Civil Engineering Dept., Birzeit University, West Bank, Palestine.
Halliday, S. P. (1994). ''An environmental code of practice for buildings and their services.'' *Proc., 1st Int. Conf. of CIB TG 16*, C. J. Kibert, ed., Braun-Brumfield, Ann Arbor, Mich., 153–162.
Hamdi, N. (1997). ''Housing alternatives: Lessons from experience.'' *The Reconstruction of Palestine: Urban and Rural Development*, A. Zahlan, ed., Kegan Paul, London, 405–420.
Handa, V. K., and De Oliveira, R. (1993). ''Affordable housing system.'' *Proc., 4th Annu. Rinker Int. Conf. on Build. Constr.*, College of Arch., University of Florida, Gainesville, Fla.
Knocke, J. (1993). ''Adequate technical quality assurance makes commercial housing finance available to third world low-income households.'' *Proc., 4th Annu. Rinker Int. Conf. on Build. Constr.*, College of Arch., University of Florida, Gainesville, Fla.
Lagos, C. P., and Handa, V. K. (1993). ''Affordable housing within existing codes.'' *Proc., 4th Annu. Rinker Int. Conf. on Build. Constr.*, College of Arch., University of Florida, Gainesville, Fla.
Mayo, S. (1997). ''Housing sector performance and housing strategy in Gaza and West Bank.'' *The Reconstruction of Palestine: Urban and Rural Development*, A. Zahlan, ed., Kegan Paul, London, 510–555.
McMurray, J. P., and Cole, A. M. (1959a). ''Code enforcement, problems and recommendations.'' *Housing Codes, Vol. 1*, New York State Division of Housing/Housing and Home Finance Agency, New York.
McMurray, J. P., and Cole, A. M. (1959b). ''Minimum housing standards ordinate.'' *Housing Codes, Vol. 2*. New York State Division of Housing/Housing and Home Finance Agency, New York.
McMurray, J. P., and Cole, A. M. (1959c). ''Administrative guide for local programs.'' *Housing Codes, Vol. 3*. New York State Division of Housing/Housing and Home Finance Agency, New York.
Overeem, J. A. (1993). ''Cost-effective residential foundation.'' *Proc., 4th Annu. Rinker Int. Conf. on Build. Constr.*, College of Arch., University of Florida, Gainesville, Fla.
Pinta, T. P., and Agopyan, V. (1994). ''Construction wastes as raw materials for low-cost construction products.'' *Proc., 1st Int. Conf. of CIB TG 16*, C. J. Kibert, ed., Braun-Brumfield, Ann Arbor, Mich., 335–342.

Stone, P. A. (1976). *Building economy*. Pergamon Press, Oxford, U.K.
Ziara, M. M., Haldane, D., and Kuttab, A. (1995). ‘‘Flexural behavior of beams with confinement.’’ *ACI Struct. J.*, 92(1), 103–114.
Ziara, M. M. (1997). ‘‘The Palestinian ministry of Housing: Challenges and opportunities.’’ *The Reconstruction of Palestine: Urban and Rural Development,* A. Zahlan, ed., Kegan Paul, London, 12–31.

APPENDIX II. NOTATION

The following symbols are used in this paper:

A_i = possible action, or alternative;
$E(D)$ = expected value of desirability;
$E(S)$ = expected value of suitability;
CA_i = associated cost of alternative;
$C(\bigcirc)$ = associated consequence of decision outcome;
C_D = adverse consequences of desirability;
C_s = adverse consequences of suitability;
D_i = ith desirability level or rating;
$\bigcirc$ = circle symbol identifying chance node in decision model;
P = probability;
$P(C_D)$ = associated probability of adverse consequences of desirability;
$P(C_s)$ = associated probability of adverse consequences of suitability;
$P(\bigcirc)$ = occurrence probability of decision outcome;
R_{ijk} = scenario’s combined weighted rating;
S_i = ith suitability level or rating;
W_{Di} = ith desirability weight factor;
W_{Si} = ith suitability weight factor; and
$\square$ = rectangle symbol identifying chance node in decision model.