A DECISION-MAKING PROCESS FOR CHOICE OF A FLEXIBLE INTERNAL PARTITION OPTION IN MULTI-UNIT HOUSING USING DECISION THEORY TECHNIQUES

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ABSTRACT. Recent demographic changes have increased the heterogeneity of user groups in the North American housing market. Smaller households (e.g. elderly, single parent) have non-traditional spatial requirements that cannot be accommodated within the conventional house layout. This has created renewed interest in Demountable/Flexible internal partition systems. However, the process by which designers decide which project or user groups are most suited for the use of these systems is quite often complex, non-linear, uncertain and dynamic, since the decisions involve natural processes and human values that are apparently random. The anonymity of users when mass housing projects are conceptualized, and the uncertainty as to the alternative to be selected by the user, given his/her constantly changing needs, are some contributing factors to this effect. Decision Theory techniques, not commonly used by architects, can facilitate the decision-making process through a systematic evaluation of alternatives by means of quantitative methods in order to reduce uncertainty in probabilistic events or in cases when data is insufficient. The author used Decision Theory in the selection of flexible partition systems. The study involved a multi-unit, privately initiated housing project in Montreal, Canada, where real site conditions and costs were used. In this paper, the author outlines the fundamentals of Decision Theory and demonstrates the use of Expected Monetary Value and Weighted Objective Analysis methods and their outcomes in the design of a Montreal housing project. The study showed that Decision Theory can be used as an effective tool in housing design once the designer knows how to collect basic data.

1. Introduction

In the selection of design alternatives, decisions are often required, irrespective of the state of completeness and the quality of information. Decisions therefore have to be made under conditions of uncertainty in the sense that the consequences of a given decision cannot be determined with complete confidence. Housing design problems are very often complex, non-linear, uncertain, and dynamic, involving natural processes and human values that are often apparently random (Lifson and Shaifer 1982). Such phenomena are naturally indeterminate and cannot be definitively described. Alternatives for future design flexibility to be given to a user involve uncertainty due to insufficient data (i.e. anonymity of user when a mass housing project is conceptualized) and probabilistic events (i.e. uncertainty as to the alternatives to be selected by the user, given his or her constantly changing needs). For quantitative purposes probability can be considered as a numerical measure of the likelihood of occurrence of an event relative to a set of possibilities (e.g. the probability that the user will implement alternative A is higher than implementing B, therefore A is recommended).

There are many methods which can be used to assist the decision-maker in the decision-making process through systematic evaluations of alternatives by means of quantitative methods. These techniques are most often used in engineering applications where exact data is available and the uncertainty of the variables is quantifiable. In most cases, the methods are very complex and involve long calculation, thereby not lending themselves readily to architectural applications. In

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architecture, there are several indeterminate factors due to the nature of housing design and human nature, as mentioned above; quantifiable methods for decision-making are not necessarily useful or appropriate. However, the author found that the Decision Theory method allowed for a great flexibility of variables, and also allowed for the isolation of elements which could be modified for architectural applications using a common-sense, intuitive approach.

Decision Theory is not commonly applied to architectural problems in general nor to housing in particular. Very often architects prefer to use visual models when decisions are made and an alternative has to be selected. Visual models have been far easier to set and manipulate than available mathematical models. Gero (Gero and Radford 1980) suggests that recent technological developments, particularly in computer science, have helped probabilistic methods to take their place alongside (but in no way to replace) visual models. Most applications of Decision Theory deal with technical aspects of housing design; however, it will be useful to review some of these cases and study the criteria applied and their assistance in the problem-solving process.

Smith and Green (1975) used probabilistic methods for quantifiable determination of subsystems in building design. They concentrated on their operational behaviour where uncertainty in predicted performance is caused by variability of demand or loading. Cost of failure was used as a performance attribute. Bayazit (1985) used a multi-variable decision-making method for the determination of priorities of building performance attributes. However, he cites "some applicability difficulties in practice because of the possibilities of large numbers of performance attributes required from designers and initiators." Davidson (1971) used decision criteria with multiple objectives to solve a problem of regional development. The decision was made based on weighing of objectives, confronting them with alternatives and ranking them using a scale of 0 to 1. This method can serve as an efficient tool for the measurement of user satisfaction in the present study. Mattar et al. (1978) used the decision-by-exclusion rule in the design of the external wall of a single-family dwelling. The application of the theory was demonstrated in three stages, and the sensitivity of decision to changes in the designer input was also considered. Initial cost was an attribute in the process as well as fire resistance, condensation and sound. In spite of the fact that the studies presented above do not demonstrate the application of Decision Theory in housing layout selection, they show its potential as a useful tool in the selection of flexibility alternatives. Prior to demonstrating the use of the technique the author wishes to outline some of its basic principles which are relevant to this study.

2. Decision Theory: Relevant Principles

In general decision problems, a framework for systematic analysis is needed. It should include the following components (Ang and Tang 1982): a list of all feasible alternatives; a list of all possible outcomes associated with each alternative; an estimation of the probability associated with each possible outcome; the criterion for decision; and a systematic evaluation of all alternatives. Those components will be elaborated below; examples will be given using the case of designing for flexibility.

Listing the feasible alternatives is a phase in the design process preceded by collection of relevant information about user needs, evaluation and synthesis. The alternatives set by the architect are several options given to the user. These concern possible changes of internal subsystems (e.g. wet or dry partitions, mechanical systems). Listing alternatives is a 'creative' stage in the design process and, for the benefit of the design solution, a large number of alternatives is preferred. The possible outcomes will be valued based on the attributes that the architect has designated to the performance variables. They can be, for example: time needed for the erection of the system in days/hours/minutes; savings to the user when compared with conventional projects and size of material needed for implementation of design alternatives. Each alternative can be associated with more than one outcome according to participants' most important variables.

A diagrammatic tool that displays the sequence of alternatives and their associated outcome is the Decision Tree (Figure 1). The branches of the tree represent either decision alternatives or chance events. Decision alternatives start at decision nodes (represented by squares); chance events start at chance nodes (represented by circles). In a 'real life' decision-making process, chance nodes will be forecasted by the architect. All paths through the tree originate at the left of the diagram with a square representing the major decision milestone that is the reason for the subsequent decisions represented in the tree and for the activities of the decision process (Raiffa 1968).

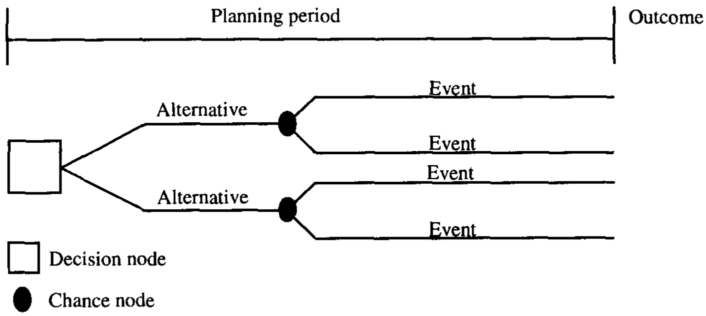

Figure 1. A decision tree

The probability that a particular alternative will be exercised is measured on a continuous scale ranging between 0 and 1. An alternative that has absolutely no chance of occurring has a probability value of 0, but on the other hand, an event that is sure to occur has a probability value of 1. The more likely an event is to occur, the higher will be its probability value which can be expressed in the following equation:

$$\text{probability that alternative A will occur} = \frac{\text{number of times alternative A occurred}}{\text{number of times counted}}$$

Ang and Tang (1975) suggested three methods to determine the probability value of an alternative: observed information, estimated from the frequency of observed events; subjective judgement of the decision-maker; and the Bayesian approach. In the last approach, the judgemental information of the decision-maker is combined with the observed information for an updated estimation of the probabilities. For flexibility problems, observed information and subjective judgement are more relevant due to the existence of studies and surveys mapping user behaviour (e.g. Teasdale 1977; Evendon 1983).

Most decisions are made under conditions of uncertainty in which performance variables of a given alternative may be stated only in terms of respective probabilities. Also, depending on the temperament, experience and degree of risk aversion of the decision-maker, the 'best decision' may mean different things to different people at different times. Nevertheless, some criteria which are relevant for a decision-making process for flexibility in housing are presented. One of these is Expected Monetary Value, a completely objective measure of the value of money. It implies that every dollar within a sum of money provides that same amount of satisfaction.

$$\text{EXPECTED MONETARY VALUE} = \sum_{j=1}^{n} X_j P(x_j) \quad (1)$$

where:

X_j = monetary value associated with alternative X
$P(x_j)$ = probability that alternative X_j will occur.

The other criterion is a Weighted Objective Decision Analysis with a determination of multi-attribute utility functions instead of single utility function. These criteria were used in environmental design primarily for the non-money attributes (Davidson 1971). The selection process is performed through summation of the contribution of alternatives to pre-determined objectives using a table (Figure 2).

Relative weights	w_1	w_2 ...	w_j ...	w_n		Overall relative utility
Alternatives	Objectives					
	O_1	O_2 ...	O_j ...	O_n		
A_1	p_{11}	p_{12} ...	p_{1j} ...	p_{1n}	U_1	$= \sum_j p_{1j} w_j$
A_2	p_{21}	p_{22} ...	p_{2j} ...	p_{2n}	U_2	$= \sum_j p_{2j} w_j$
:						:
A_i	p_{i1}	p_{i2} ...	p_{ij} ...	p_{in}	U_i	$= \sum_j p_{ij} w_j$
:						:
A_m	p_{m1}	p_{m2} ...	p_{mj} ...	p_{mn}	U_m	$= \sum_j p_{mj} w_j$

A_i = The ith alternative, $i = 1$ to m

O_j = The jth objective, $j = 1$ to n

w_j = The relative weight of importance to objective O_j, $j = 1$ to n

p_{ij} = The probability of attaining objective O_j through alternative a_i

U_i = The overall relative utility of alternative a_i

Figure 2. Principle of weighted objective decision analysis
Source: Ang and Tang (1982)

The decision criteria are instrumental in the selection of alternatives. In housing problems, where monetary and human values are often mixed, the lack of a tool that combines both is evident.

It may require the use of several criteria that cover both sets of values. Following the selection of the relevant criteria a systematic evaluation of all alternatives is made. The preferred alternative, or sequence of all alternatives, is selected on the basis that it represents the needs and objectives of all the participants.

3. Demonstration

The author selected a dwelling in a typical low-rise three-storey wood-frame walk-up apartment building in Montreal (Friedman 1987). Five flexibility design options (called alternatives) were suggested for the unit. The plan (Figure 3) and the description of their use is presented below:

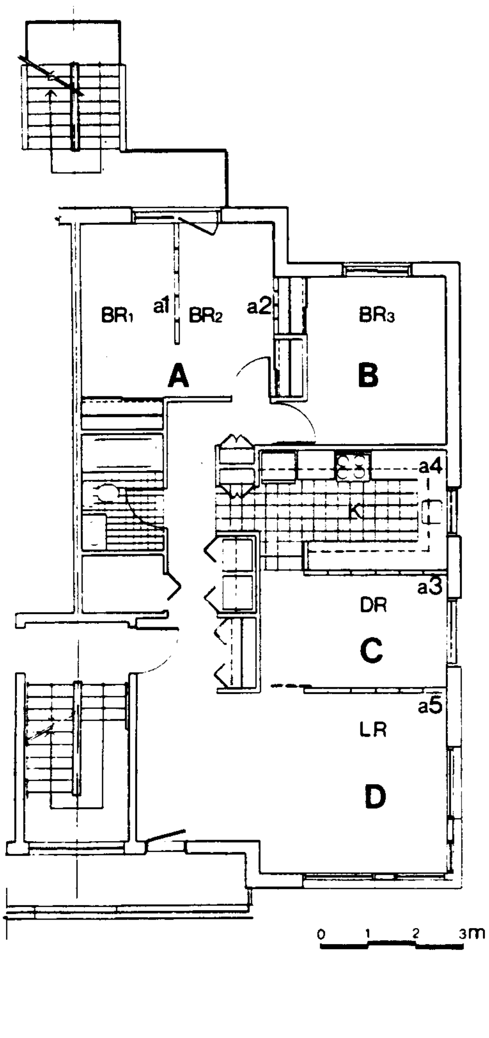

Figure 3. Plan showing the five flexibility options

ALTERNATIVE 1 : *Demountable wall dividing room A.*
Description of Use: Upon occupancy dual-headed households without children can a) use room A as a master bedroom and store the partition, b) use room A with the dividers for their personal use (studies) or c) when children are born room A can serve as two bedrooms.

ALTERNATIVE 2: *Demountable wall section, divider between rooms A and B.*
Description of Use: If room B is used as a master bedroom (dual-headed households without children), wall 2 can be folded and stored to make more space.
When a child is born, the crib can be in room A and easy access can be provided at night when care is needed.
When a second child is born and/or when privacy is required when they attend school, the partition can be closed and more closet space can be added.

ALTERNATIVE 3: *Enclosure of kitchen space.*
Description of Use: Dual-headed families without children can have the partition removed and stored if wanted to allow open space between the LR and the kitchen. When children are older and/or more consumer goods are purchased, the partition can be re-installed and more kitchen cabinets added.

ALTERNATIVE 4 : *Installation of mechanical and electrical service lines to allow future dismantling of kitchen.*
Description of Use: Pending their economic priorities, buyers may upgrade kitchen cabinets, appliances and finishes. To facilitate this, mechanical and electrical service lines have to be installed in a flexible manner.

ALTERNATIVE 5: *Demountable divider between the LR and the DR.*
Description of Use: When children are born and play space is needed, the wall can be removed. The same wall could also have been removed upon occupancy and stored and re-installed when a definite space for DR is required.

The author then evaluated the above design alternatives. Prior to the evaluation process he assessed each alternative and summed up the outcome in Table 1. It is important to mention that these alternatives were selected based on their contribution to the long-term economic objectives (i.e. return on initial economic investment). The architect displays the collected data on a Decision Tree (Figure 4) and uses the Expected Monetary Value criterion in the selection process.

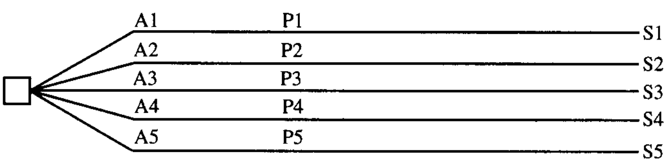

Figure 4. The decision tree

$$EMV = \sum_{j=1}^{n} S_j P(S_j) \qquad (2)$$

$EMV\ 1 = 500 \times 0.9 = 450$

$EMV\ 2 = 250 \times 0.5 = 125$
$EMV\ 3 = 700 \times 0.2 = 140$
$EMV\ 4 = 400 \times 0.7 = 280$
$EMV\ 5 = 250 \times 0.75 = 150$

Based on Expected Monetary Value, alternatives A1 and A4 will maximize the contribution to the user's objectives. In spite of the fact that alternative A3 promises the highest future savings potential, its probability of execution is the lowest. The author therefore selected those alternatives that yielded the highest values of S.

TABLE 1. Evaluation of design alternatives

Alternatives		*S*	*P*
A_1	Demountable wall dividing room A	500	0.9
A_2	Demountable wall section, divider between rooms A and B	250	0.5
A_3	Enclosure of kitchen space	700	0.2
A_4	Installation of mechanical and electrical service lines to allow future dismantling of kitchen	400	0.7
A_5	Demountable divider between the LR and the DR	250	0.75

where:

S = assumed Life Cycle Savings potential in dollars (minimum residency period of eight years). All figures were calculated based on contractors' estimates and the autor's field research for the cost of labour and materials in Canadian dollars

P = the probability that the user's investment will result in economic benefits in the residency period. The probability values are based on observed information (i.e. survey of occupied projects) and on the architect's subjective judgement

4. Weighted Objective Decision Analysis

When one of the participants (in this case an architect and a builder) has more than one objective, which is most often the case, a Weighted Objective Decision Criterion can be used. In the following examples, the builder listed his objectives to the architect who processes and uses them in the selection of alternatives. The objectives are:

01 - The alternatives proposed to the user will be those which can promote sale (i.e., are known to be a marketing device)

02 - The implementation of the alternative will not require more than two meetings with the user.

03 - Not more than two different trades will be involved in the installation of each alternative.

04 - The installation of the alternative will not last more than two extra working days per apartment.

4.1. RELATIVE WEIGHTS OF OBJECTIVES

The author used ordinal ranking in which he lists the alternatives in decreasing order of importance (Table 2).

TABLE 2. Alternatives in decreasing order of importance

Weights	Rationale
01>02	The builder sees sale potential as a prime objective due to stiff competition in the area and loan constraints.
01>03, 01>04	The builder does not mind having an extra meeting with some of the users. However additional trades will raise the cost of flexibility and will increase construction time.
04=03	Based on the builder's calculations, the use of trades is equivalent to the addition of two working days.
01>03 + 04	High sale potential is more important to the initiator than objectives 03 and 04 combined.

4.2. RELATIVE RANKING OF OBJECTIVES

Subsequently a cardinal ranking of each of the objectives is established; the relative importance of each of the objectives with respect to the others is evaluated by assigning each of them a numerical weight. Starting with the most important objective, an arbitrary weight (e.g. 100) is assigned. Next, numerical weights are assigned to each of the other objectives. The set of initial weight assignments is then cross-checked for consistency with the preference statement in the ordinal ranking (Table 3).

4.3. RELATIVE UTILITY OF ALTERNATIVES

The next step in the decision analysis included a listing of the above alternatives and the assignment of probabilities (p_{ij}) that were formed earlier, based on objective information and the architect's subjective judgement. Finally, the overall relative utility of each alternative is computed as in Figure 5 (Ang and Tang 1982):

$$U_i = \sum p_{ij} W_j \quad . \tag{3}$$

TABLE 3. Cardinal ranking of objectives

Objectives		Rank 1st attempt	Rank re-evaluation	Rationale
01	Marketing device	100	100	
02	Maximum 2 pre-occupancy meetings	25	25	
03	Maximum 2 trades	75	50	Both 03 and 04 seem to be equal to the builder in their importance in comparison to 01
04	Maximum 2 working days	75	50	

The recommended alternative is the one which has the maximum relative utility. In the above example, alternative A5 seems to be the one which will maximize the contribution to the builder's objectives. Weighted Objective Decision Analysis provides a useful means by which many objectives of a participant can be evaluated through the assignment of probability values.

Relative weights	$W_1=100$	$W_2=25$	$W_3=50$	$W_4=50$	
	Objectives				Overall relative utility
Alternatives	01 Marketing device	02 Meetings	03 Trades	04 Working days	
A_1 Demountable wall dividing room A	0.7	0.2	0.8	0.6	145
A_2 Demountable section divider between room A and B	0.9	1.00	0.3	0.5	155
A_3 Enclosure of kitchen space	0.2	1.00	0.7	0.6	110
A_4 Mechanical and electrical system for dismantling	0.8	0.3	0.5	0.3	127.5
A_5 Demountable divider between LR and DR	1.00	0.95	0.4	0.3	158.75

Figure 5. Relative utility of alternatives

5. Conclusions

Architects in North America tend to rely on a variety of models in their decision-making process,but rarely on scientific ones. In housing, the need to incorporate the builder's objectives into the design provides an opportunity to experiment with other models since most of his decisions are based on quantifiable attributes (e.g. economic). In the above demonstration the author showed that Decision Theory can be a useful tool in combining a range of attributes. Expected Monetary Value proved to be a simple technique for deciding what the probability value in the application is going to be. That determination counts for most of the successes and the reliability of the applications. In examining the results in the above demonstration, the author believes that they make sense with regard to family space needs through its life cycle.

The Weighted Objective Decision Analysis technique, although more complicated, provides margin for adjustment to the needs of the decision-maker. The primary advantage of the technique, in the author's opinion, is the inclusion of a subjective approach in the process. The architect can list all of his/her options and assess them. To conclude, Decision Theory can be a useful tool when quantifiable attributes are combined with other factors in the decision-making process.

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