Conjoint measurement applied to the judgement and design of dwellings

CONJOINT MEASUREMENT APPLIED TO THE JUDGEMENT AND DESIGN OF DWELLINGS:

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1. Introduction

The issue of user participation in the design of dwellings has received major attention during the past few years. Although there now exists some degree of agreement concerning the importance of user participation in the design process, the question of the form of such participation is still open for debate. A major approach among the available alternatives is characterised by an iterative process whereby users express their desires and architects attempt to accomodate these issues in some design.

A possible criticism on such an approach concerns the amount of work involved and the lack of knowledge about the possible trade-offs that users make to arrive at a decision. One would reach a lot of improvement if one could explicitly measure these trade-offs and derive an optimal design from a set of systematic measurements of users' evaluations of hypothetical attributes of dwellings. A measurement approach, known as conjoint measurement or conjoint analysis, constitutes, in theory at least, a flexible approach to solving this question. However, to the authors' knowledge, this approach has hardly been empirically tested in the context of the judgment and design of dwellings.

The purpose of the present article therefore is to outline, test and assess one appropriateness of conjoint measurement for measuring trade-offs and generating optimal designs for dwellings. The paper is organized as follows. First, in the next section, the fundamentals of conjoint measurement will be outlines. This is followed, in sections 3 and 4, by a discussion of the results of an experiment involving this approach. Section 5 then shows how designs can be generated from the results of a conjoint analysis. The paper is concluded with a short summary.

2. Conjoint measurement

Consider a multiattribute choice alternative, for example a dwelling, which can be described as the ordered m-tuple

$$x = (x_1, x_2, \ldots, x_j, \ldots, x_m)$$

where xj is the level of alternative x on the jth attribute. Assume that the choice alternative can be characterised by a set of attributes or factors, e.g. type of dwelling, lay-out, price etc. Then, each choice alternative may be defined in terms of its levels on the various factors or attributes.

Assume that individuals attach some evaluation to each attribute level and that they arrive at some overall evaluation of each alternative by subjectively combininig their part-worth utilities according to some algebraic rule.

The problem then is how a representational mathematical model can be identified and how the utilities can be measured. Several approaches can be used for solving this problem. The compositional approach is based on the assumption that the overall utility for a multiattribute choice alternative can be obtained as some function of the alternative's perceived attribute levels as separately and explicitly evaluated by an individual. Hence, individuals are typically requested to evaluate each alternative on a number of attributes and indicate the importance of these attributes. The overall utility for a choice alternative is then obtained by combining their scores into some overall value. A critical assumption underlying the approach is its assumption that individuals can provide valid and accurate evaluations of attributes independently of any specific context.

In contrast, conjoint measurement is based on the notion that it may be possible to measure the relative effects of two or more attributes even though their individual effects may not be measurable properly. Conjoint measurement models attempt to derive part-worth utilities defined on the levels of the attributes by decomposing some overall utility measure into scale values for the attribute levels given some type of composition rule. More specifically, conjoint measurement is concerned with simultaneously scaling the dependent variables such that a priori specified composition rule preserves the manifest preference order relationships in the data as closely as possible (Luce and Tukey, 1964; Krantz, 1964).

The approach typically involved the following steps. First, a composition rule or measurment model which describes the combination of individual effects is specified. Two frequently employed rules are the additive and the multiplicative rule. The additive rule assumes that an overall utility is the sum of a set of independent effects. It accounts for compensatory decision-making processes in that a low evaluation value on some attribute can, at least partially, be compensated by high scores on one or more of the remaining attributes.

The multiplicative rule assumes that an overall evaluation is the product of a set of effects defined on the attribute levels. It assumes that a low subjective evaluation value on some attribute will result in a low overall evaluation score, and, hence, it represents noncompensatory decision-making processes.

The next step involves data collection. That is, the researcher defines a set of relevant attributes and attribute levels which are then combined according to the principles of experimental design. If the number of attributes and attribute levels is small, a full factorial design would be appropriate. It involves combining the attribute levels in every possible way. Thus, 3 attributes with 3 levels each would result in 3.3.3=27 combinations. However, as the number of attributes or attribute levels becomes larger, the experimental task for the subjects would become too demanding. In this case, trade-off designs or fractional factorial designs would be more appropriate since they limit experimental labour. The combinations of the attribute levels constitute descriptions of hypothetical choice alternatives. Subjects are then typically requested to rank these hypothetical choice alternatives with respect to their overall evaluation. Subsequently, the part-worth utilities of the attribute levels (stimulus interval scales with common unit) are derived such that the ordering of the choice alternatives, predicted by the composition rule, is as nearly monotonic with the observed rank ordering of the choice alternatives as possible. Techniques such as multidimensional scaling, linear programming or (logistic) regression analysis may be used for deriving the part-worth utilities depending upon the assumptions regarding the dependent variable and the model's error terms. The most appropriate composition rule for a given decision-making task may be identified by comparing the values for some goodness-of-fit measure. A more detailed account of experimental designs, estimation techniques and methodological issues associated with conjoint measurement models and related approaches is provided elsewhere (Timmermans, 1984).

The results of the analysis provide information regarding the type of decision-making process a subject has adopted, a set of utilities for the attribute levels and the importance weights a subject attaches to the different attributes. This information can then be used to assess alternative designs of, for example, dwellings. Alternatively, it can be used to indicate which attributes are considered most important and hence should be optimized in order to create new designs for which a subject's evaluation is expected to be good.

3. The experiment

The main purpose of the present study was to test whether the conjoint measurement model, which has been employed successfully by some of the authors in different context (e.g. Timmermans et al, 1984; Veldhuisen and Timmermans, 1984), could well be employed in the process of evaluating and designing dwellings. Several tests on the validity and reliability of the model were performed. However, due to the limitations in the length of the present paper, we will only present the main findings of the analyses.

Subjects. In total 20 subjects participated in the experiment. All subjects were paid for participating. They were selected on the basis of some back ground variables concerning socio-economic variables and residential history. The sample was diverse in terms of these variables.

Stimuli and experimental design. In total 10 attributes, each with three levels, were selected, Their definition is provided in table 1. To avoid information overload the following balanced design was used to generate the hypothetical dwellings.

Table 1. Attributes and attribute levels.

Attribute	Attribute 1	4	5	9	10
2	x	x			x
3	x		x	x	
6	x	x		x	
7		x	x		x
8			x	x	x

Attribute	Levels
1. Type of kitchen	-fully separated from living room
	-partially separated through kitchen bar
	-open kitchen
2. Location of kitchen	-in the front towards the street (F,D)*
	-in centre of the dwelling (E)
	-in the back towards the garden (A,B,C,)
3. Sun in kitchen	-no sun at all
	-sun only in the morning or afternoon
	-sun throughout the day
4. Size of the kitchen	-small
	-medium
	-large
5. Location of living room	-across the width of the dwelling at the side** of the street
	-across the depth of the dwelling (A,B,C,E)
	-across the width of the dwelling towards the side of the garden (D,F)
6. Sun in living room	-see under 3
7. Size of the living room	-see under 4
8. Size of parents' bedroom	-see under 4
9. Size of remaining room	-see under 4
10. Location of staircase	-in hall (A,C,D,E,F)
	-in living room at the side
	-centrally located in living room

* see also figure 3
** impossible in a single-family house with front entrance.

Each combination yields a trade-off matrix involving 3.3=9 hypothetical dwellings varying on two atttibutes only. Subjects were told to assume that the remaining attributes are independent of those used in the trade-offs. A combination of verbal descriptions and sketches was used to present the hypothetical dwellings. The sketches should provide an impression of parts of the dwelling, not only in terms of its lay-out but also in terms of its furnishing.

Each combination of the attribute levels was printed on an index card. Prior to presentation to each subject all cards were randomized. Each subject was then asked to sort the index cards from most preferred to least preferred. The result of this procedure is a strict rank order of 9 combinations of two attributes for each trade-off matrix and each subject. In addition, subjects were asked to evaluate a limited number of these combinations on a 8-point verbal category scale, ranging from extremely bad to excellent.

The same scale was used to measure a subject's evaluation of each attribute separately. Moreover, each subject was requested to express the importance he/she attaches to each attribute. Subjects were asked first to select the most important attribute and then to indicate the importance of the remaining attributes are compared to the importance of the most important attribute on a 5 point verbal category scale,

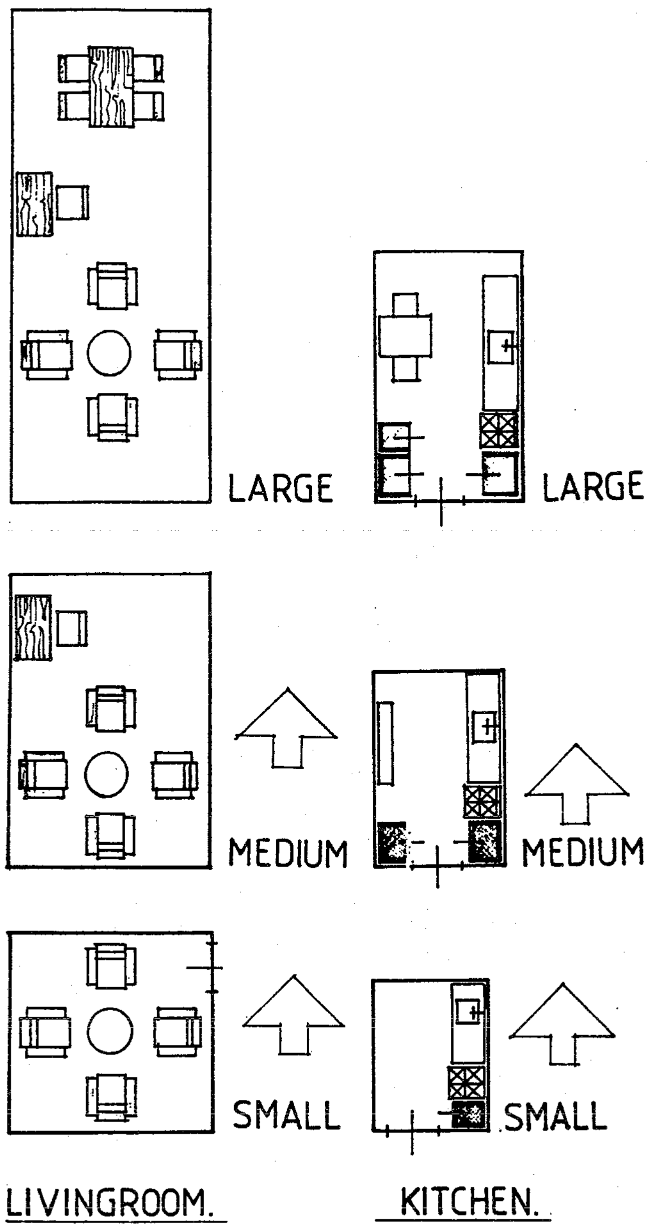

Figure 1. Some examples of the sketches presented to the subjects

ranging from equally important to totally unimportant. Finally, importance scores were also obtained by means of a 0-100 mm. graphic rating scales.

4. Analysis and results

Two analyses are particularly important for the present article. First, the average evaluation and importance weight for each attribute was calculated on the basic of the direct, self-explicated, measurements. Secondly, part-worth utilities were derived for each attribute of the dwellings, given an additive conjoint measurement model.

The results of the first analysis are given in table 2.

Table 2. The average evaluation and importance weights

	Average	
	Importance weight	Evaluatio
1. Type of kitchen	0,71	
_fully separated from living room	0,81	0,63
_partially separated through kitchen bar	0,78	0,56
_open kitchen	0,79	0,50
2. Location of kitchen	0,83	
-in the front towards the street	0,75	0,47
_in centre of the dwelling	0,85	0,38
_in the back towards the garden	0,80	0,77
3. Sun in kitchen	0,75	
_no sun at all	0,73	0,37
_sun only in the morning or afternoon	0,80	0,70
_sun throughout the day	0,80	0,42
4. Size of the kitchen	0,88	
_small	0,78	0,26
_medium	0,81	0,67
_large	0,80	0,75
5. Location of living room	0,91	
_across the width of the dwelling at the side of the street	0,73	0,47
_across the depth of the dwelling	0,69	0,58
_across the width of the dwelling towards the side of the garden	0,80	0,73
6. Sun in living room	0,90	
-no sun at all	0,83	0,12
-sun only in the morning or afternoon	0,87	0,64
-sun throughout the day	0,82	0,64
7. Size of the living room	0,97	
_small	0,87	0,17
_medium	0,84	0,52
_large	0,92	0,80
8. Size of parents' bedroom	0,74	
_small	0,84	0,37
_medium	0,78	0,58
_large	0,76	0,67
9. Size of remaining rooms	0,74	
_small	0,79	0,35
_medium	0,77	0,61
_large	0,75	0,70
10. Location of staircase	0,76	
_in hall	0,80	0,76
_in living room at the side	0,79	0,40
_centrally located in living room	0,74	0,24

Table 2 clearly demonstrates the attributes of the living room are considered to be the most important and that the subjects almost without exception, prefer a large living room. The attributes of the kitchen are the next most important, while the remaining attributes are in the average less important for the subjects.

An additive model was used to derive the part-worth utilities. Techniqually, a gradient search algorithm was used to derive these utilities. The direct measurements of the attribute evaluations were used as starting values, which were subsequently iteratively adjusted for each attribute level in order to minimize the total number of incorrect pairwise orderings of combinations in the trade-off matrices. The analysis was repeated with weighted direct measurements of the attribute evaluations as starting values. The results of these analyses are given in table 3, which provides the total number of correct rank orderings for the unweighted the weighted and for the pairwise two-by-two orderings respectively. Table 3 clearly demonstrates that the trade-offs can be predicted resonably on the basis of the direct

Table 3. Percentage of correct predictions

	Percentage			
Subject	B	C	D	
1.	53,6	62,0	93,1	
2.	80,0	79,6	96,3	B:Unweighted
3.	70,8	74,8	88,7	C:Weighted
4.	71,7	76,0	91,1	D:Final
5.	81,1	81,7	92,4	

6.	87,2	88,2	97,4
7.	77,4	77,6	90,0
8.	84,3	84,1	95,9
9.	76,3	75,0	92,8
10.	85,0	81,3	98,0
11.	85,2	85,2	93,1
12.	80,6	83,2	90,9
13.	69,1	71,3	89,4
14.	84,6	86,9	94,6
15.	79,1	83,6	92,0
16.	63,2	73,4	89,6
17.	89,7	90,4	95,4
18.	78,5	77,1	94,4
19.	80,4	77,0	90,7
20.	75,2	76,0	90,2

measurements. In general, the percentage of correct predictions still increases if one uses the weighted measuremnts. The percentage of correct rank orderings in the final solution is satisfactory. It ranges from 88.7% for subject 3 to 98.0% for subject 10. The derived part-worth utilities are given in table 4, which suggests the existence of quite large differences in utilities between subjects. However table 4 also indicates that a few clusters with a similar pattern of

Table 4. The calculated part-worth utilities according to the additive composition rule

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Kitchen																				
separated	34	48	45	43	55	38	39	30	93	58	85	58	36	11	1	12	99	64	55	11
partially sep.	25	31	54	57	21	30	29	28	46	43	69	63	27	77	42	39	74	48	27	40
open	33	12	38	40	1	16	19	25	1	55	47	56	4	77	52	12	66	34	15	40
Location kitchen																				
streetside	39	45	10	25	74	51	48	1	47	36	86	40	51	18	60	70	1	1	25	70
in centre	11	31	1	7	17	69	19	72	27	34	58	55	56	1	36	68	64	67	38	39
gardenside	49	65	77	39	85	79	85	70	15	60	73	90	60	50	99	75	90	52	45	48
Sun in kitchen																				
no sun	38	99	1	57	1	1	19	16	49	56	69	70	42	1	12	19	19	15	58	20
half the day	61	49	94	90	15	49	60	45	22	76	86	77	61	15	88	72	35	26	76	40
all day	77	1	23	28	28	28	24	71	7	87	48	72	5	7	16	34	45	21	47	11
Size of kitchen																				
small	77	14	1	40	52	27	26	25	14	27	1	17	58	5	35	46	62	37	9	54
medium	77	49	35	76	58	61	27	50	19	63	36	41	74	25	98	75	74	55	30	58
large	56	64	86	84	61	91	29	70	27	87	38	44	26	41	15	51	76	84	56	52
Location living room																				
streetside	63	84	64	54	38	33	24	42	1	45	4	43	17	1	88	69	52	1	19	77
accross depth	77	99	37	76	99	57	48	51	23	80	25	90	55	41	29	77	70	26	44	65
gardenside	70	81	1	78	46	43	25	51	56	90	73	65	41	18	99	63	96	58	57	90
Sun in livingroom																				
no sum	37	37	1	22	16	3	37	37	57	9	21	43	6	1	11	15	44	1	33	11
half the day	58	79	61	56	56	52	69	64	73	60	90	65	66	49	68	77	79	56	75	90
all day	77	99	34	26	95	82	42	83	32	81	14	90	57	15	94	48	87	70	46	52
Size of livingroom																				
small	52	1	1	1	21	1	29	28	1	9	1	32	20	1	7	11	56	1	9	11
medium	64	41	43	28	50	35	41	64	29	54	24	54	58	29	56	58	84	39	40	71
large	25	69	76	36	99	79	57	45	69	74	39	90	90	84	99	46	91	77	80	77
Size parents' bedroom																				
small	44	58	15	73	15	35	21	55	28	54	21	3	49	1	30	49	79	38	9	89
medium	49	85	29	90	28	79	40	99	55	70	63	30	39	36	68	52	90	38	39	90
large	25	96	7	69	1	93	57	81	97	80	34	68	34	66	74	11	99	37	57	58
Size of remaining rooms																				
small	58	70	1	1	28	23	54	45	40	57	1	5	19	6	37	12	69	26	31	43
medium	77	96	17	20	72	57	72	77	50	75	49	78	56	30	86	35	84	45	80	48
large	58	97	39	18	99	77	62	56	63	90	32	90	89	89	90	34	94	61	90	30
Location staircase																				
in hall	64	47	52	74	71	97	47	58	56	76	90	81	40	61	91	77	48	43	63	58
in livingroom	56	34	80	36	30	38	25	34	51	42	41	62	24	90	58	73	20	30	51	25
central	45	1	42	1	1	1	19	30	41	13	3	63	6	34	1	62	1	1	31	15

part-worth utilities can be identified, implying that a limited number of designs would be suffice.

5. Generating optimal designs

The conjoint analysis results in a set of part-worth utilities for each individual subject. Now suppose that the values as indicated in table 5 have been obtained. We wish to generate an optimal design, given these figures. Table 5 shows that such a design accomodates the

Table 5. Hypothetical part-worth utilities

1. Type of kitchen		
_fully separated from living room	47	-14
_partially separated through kitchen bar	61	max
_open kitchen	44	-17
2. Location of kitchen		
_in the front towards the street	36	-63
_in centre of the dwelling	1	-98
_in the back towards the garden	99	max
3. Sun in kitchen		
_no sun at all	14	-80
_sun only in the morning or afternoon	94	max
_sun throughout the day	45	-49
4. Size of the kitchen		
_small	1	-78
_medium	38	-41
_large	79	max
5. Location of living room		
-across the width of the dwelling at the side of the street	71	max
-across the depth of the dwelling	67	- 4
-across the width of the dwelling towards the side of the garden	31	-40
6. Sun in living room		
-no sun at all	22	-58
-sun only in the morning or afternoon	80	max
_sun throughout the day	58	-22
7. Size of the living room		
_small	41	-49
_medium	57	-33
_large	90	max
8. Size of parents' bedroom		
_small	77	- 2
_medium	79	max
_large	71	- 8
9. Size of remaining room		
_small	53	-30
_medium	76	-13
_large	83	max
10. Location of staircase		
_in hall	82	-12
_in living room at the side	94	max
_centrally located in living room	73	-21

following attributes: a kitchen half separated from the lving room, a kitchen located towards the garden, a large kitchen, the living room located from the front to the back of the dwelling, a large living room and the staircase to the side of the living room. For these conditions a trade-off exists between the size of the kitchen and the size of the living room since the total amount of available space is limited (in this case to 40 m^2). Table 5 shows that the loss in utility per m^2 for the kitchen is 41/(42.2-8.6)=11.4, while this loss is 33/(31.0-18.6)=2,7 for the living room. The figures between parentheses correspond with the sketches, used in the experiment. Hence, an optimal design would involve 28.8 m^2 for the living room and 12.2 m^2 for the kitchen. Fig. 2 presents the design of the resulting floorplan.

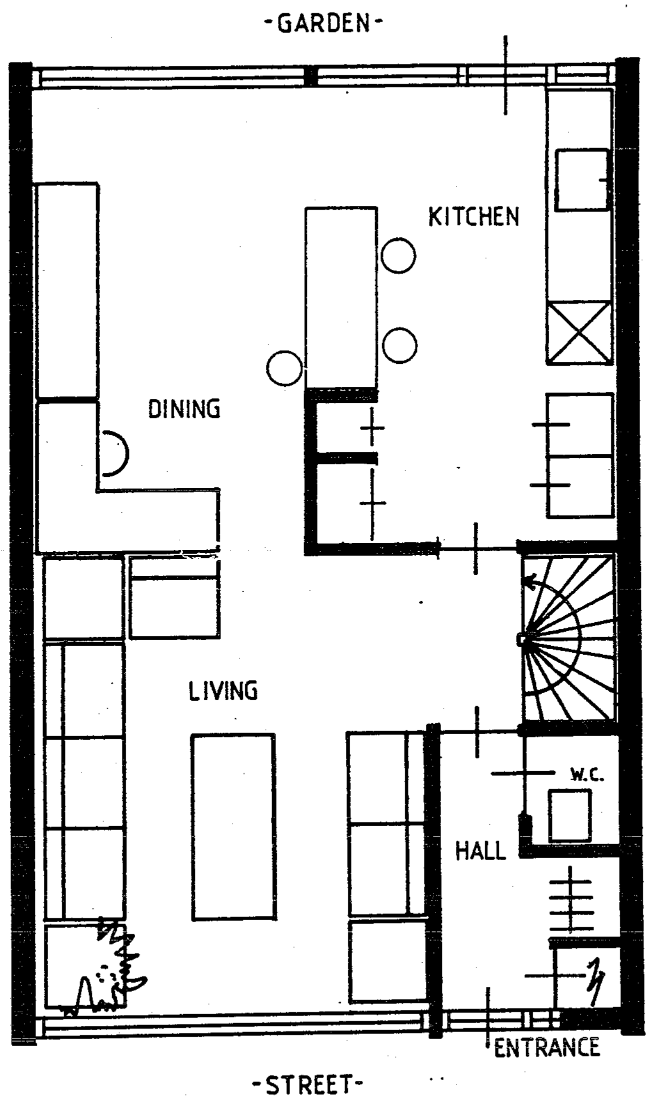

Figure 2. The design of a floorplan for a hypothetical subject.

This approach resulted in a design for each subject. Next, these designs were averaged to yield a set of 6+3 distinct designs. In figure 3 the 6 designs are denoted with A through F. The 3 designs show a different position if the kitchen, the "meanderform" but do not differ in utility from the corresponding designs.

All these designs could be realized within the support structure, as indicated in fig. 4, which is based on a zoning system using the depth measures 600, 1500, 600, 900, 600, 900, 600, 900, 2400, 600 mm. The total depth of the dwelling is 9000 mm.

Finally the nine designs were adjusted to the support structure. The resulting designs are shown in figure 5.

To test the validity of these designs, all nine designs were presented to each subject eight months after they had completed the main experiment. Each subject was asked to rank order these designs in terms of overall preference. 17 out of the 20 subjects indicated the design for which their predicted utility, using an additive composition rule, was highest, as the design of their first or second choice. For the multiplicative rule, the preference of 15 sujects was predicted correctly, while the choice of the remaining 5 subjects was predicted as their second preference. This is a satisfactory result, especially as the differences between the designs

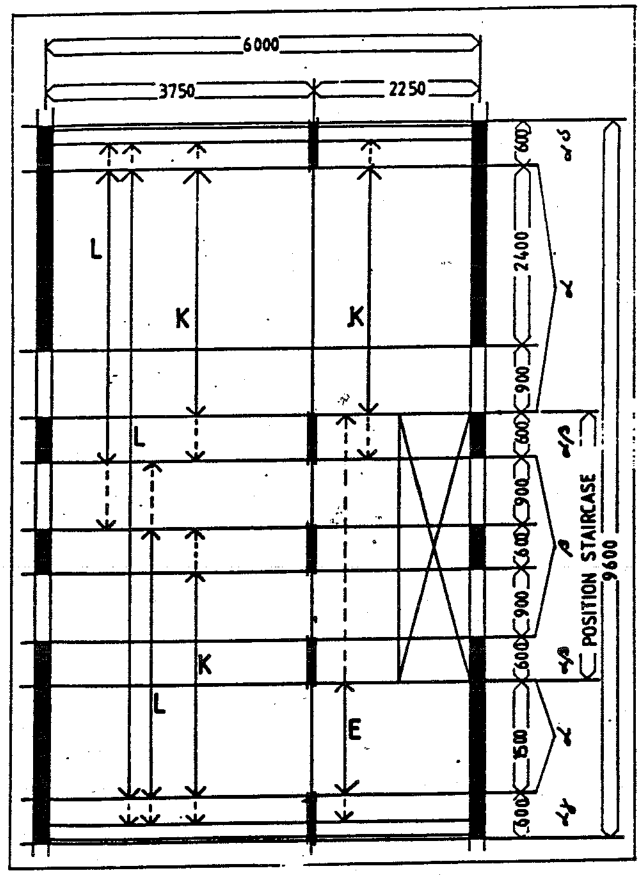

Figure 4. The support design for the nine floorplans.

are very limited. The fact that the multiplicative composition rule shows better results than the additive rule points to the existence of very low utilities of elements in some of the designs which are not compensated low by higher utilities of other elements.

It appeared further that deviations were due to a number of reasons. Some subjects explicitly indicated that they had changed their preferences between the two measurements. Others changed their preferences after seeing the generated designs.

After the choices were made the subjects were shown the designs, adjusted to the support structure (figure 5) and explicitly asked whether they would change their mind because of the inherent differences. Except for one of the subjects nobody considered it necessary to change his/her mind.

6. Conclusion

The main thrust of the present article has been to test the validity of conjoint measurement models in the process of evaluating and designing dwellings. The findings of the study generally support the approach. The validity and reliability of the conjoint measurements appears to be satisfactory, while the desings developed on the basis of the derived utility values are by most subjects seen as optimal designs given their personal circumstances.

7. Literature

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Figure 3. The 9 designs of floorplans for all the subjects.

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Figure 5. The nine designs adjusted to the support design.

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