AUTOMATED GENERATION OF RESIDENTIAL ROOM-LAYOUT WITHIN A CONSTRAINED COVERED AREA

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Abstract. A significant quantum of all buildings constructed in modern times is designed for residential purpose. A tremendous amount of money is being spent every year for construction of residential buildings. Therefore, optimization of design becomes very important. In a country like India most people in urban area live in houses having constrained area. A significant part of residential units comes under mass housing either as high-rise building blocks or as plotted developments. In any of such schemes there are large number of housing units for a group of families of whom general characteristics are known but characteristics of individual families are not known at the time of designing. This situation is, however, suitable for scientific investigation and analysis based on statistical surveys. Broadly speaking, this paper suggests approach to deal with this situation of finding optimum layout of rooms of a housing unit for any target group of families when the covered area is so constrained that freedom of using different criteria like aesthetics, structural systems, materials and methods of construction in varieties of ways is drastically reduced. In such constrained area for housing units rooms are generally found rectangular within overall rectangular outline of each unit. Method shown here is valid under this restriction. It is also assumed that number of rooms will be restricted to such number that exhaustive search for design is practically possible within a reasonable time with present day capabilities of normally available PCs.

1. Introduction

A significant number of buildings in our country are meant for residential use. Out of these, very few are properly designed. Moreover, there is an acute shortage of houses in our country. This situation requires very fast method of getting near-optimum design. Even though tremendous money is being spent every year in construction of residential houses proper care in getting a near-optimum design is not taken mainly because of lack of awareness, shortage of time and absence of proper method to generate and evaluate the design faster. Due to this situation tremendous loss has to be borne by our society in terms of quality achieved against a given expenditure. Therefore, a systematic, fast optimum-design-generating procedure is required to tackle the problem efficiently. Broad objective of this paper, therefore, is to develop a method by which a suitable residential plan for small units can be prepared automatically by using computer.

2. Some Basic Concepts

2.1. DESIGN INPUTS

Finance, land area, materials, labors, tools and techniques of construction, tools and techniques of designing, etc. are the ingredients and implements (in general will be referred to as *design inputs*) by which residential units are to be produced in practice. Any variation in availability of these inputs will mean variation in quality of the design. Therefore, product of a residential unit is a function of these inputs.

2.2. CONSTRAINTS

There can be three types of *constraints*. (a) Limitations on design inputs, mentioned above, act as constraints towards attainment of better quality of a residential unit. For example, limitation of available area is a serious constraint. (b) Similarly, surrounding facilities infrastructures, physical and social environments, any requirements imposed by statutory rules, etc. may dictate the outcome of the design of the system under consideration. Therefore, these are also constraints. (c) Goal of the design or design brief may also dictate certain mandatory restrictions to be observed in the design. These are also to be considered as constraints.

2.3. CRITERIA

Broad distinct *criteria* to judge the quality of a residential unit are well known. These are: economy in cost, functional convenience, thermal comfort, aesthetic quality, safety and security, privacy, stability and durability, sustainability, etc. Moreover, any broad criterion, mentioned above, may contain many sub-criteria. For instance, functional convenience may contain criteria like (i) presence of different types of rooms and spaces, (ii) their adjacency, (iii) their sizes, (iv) service facilities, etc. Normally these criteria or sub-criteria are implicitly known to architects or explicitly spelt out in the stated goal or in the design brief. For a given design problem of a residential unit, there can be many possible good alternative solutions. These solutions can be evaluated based on the above criteria considering each separately. Each alternative design may satisfy different criterion of the set in different magnitudes

It is well known in architecture that for a given problem there may be many possible solutions. One design is to be selected based on how different criteria are satisfied by the available designs. Problem of selection arises when one design is better than the other from the point of view of certain criteria while other design is better based on remaining criteria. If we try to improve upon a given criterion other criteria may start loosing values. This means in architecture criteria are generally conflicting in nature. In such case value (v) of a design is a complex function of all criteria $c_1, c_2, c_3, \ldots$

$$v = f(c_1, c_2, c_3, \ldots) \quad (1)$$

But under certain conditions we may find some criteria when one criterion may remain independent of other criterion or not significantly influenced by the other. For instance, quality of toilet furnishing and the quality of roof finishing or quality due to room height and quality due to room-layout are not significantly related to each other. We can go on adding quality of one criterion keeping quality of other criterion fixed. In such cases:

$$v = w_1 . f(c_1, c_2, \ldots \ldots) + w_2 . g(c_3, c_4, c_5, \ldots) + \ldots \quad (2)$$

This situation helps us improving design without much botheration. We will exploit this situation in our design process.

3. Analysis of the problem

The problem under consideration is analyzed developing three concepts detailed below.

3.1. CONCEPT OF "CONSTRAINED COVERED AREA"

When some of the inputs are made more stringent, possibility of variations in design reduces because of reduction in available varieties of inputs. For example, with the reduction of "available covered area" possible varieties of different inputs like finance, varieties of materials, labors, tools and techniques of construction are also reduced in addition to the available area.

Therefore, it will cause reduced variations in outputs resulting in reduction in values of different criteria. Under this new situation characteristics of criteria to be used for evaluation may change. It may happen that, under this situation, change in quality in one criterion will not affect the quality of other criterion – they become independent of each other as depicted in equation (2). For example, with the reduction of "available covered area", possible varieties under criteria like aesthetic quality, cost, stability and durability, etc reduces and they start contributing to the overall value of the design independently without creating any interference with the contribution of other criteria. Under this situation designing become simpler – significant criteria which has more flexibility can be dealt with first for getting optimum design from the point of view of that criteria and subsequently remaining criteria may be dealt with to enhance the quality of the design.

As an example, when available covered area is less than 110 SqM for a unit with two bed rooms, two toilets, one sitting room, one dining room, one kitchen and one balcony, contribution of most of the criteria start showing independence. Further reduction of area maintains the same property until it reaches an area below which no layout for a given set of rooms is acceptable unless a different objective is set for the problem. For instance, for the above requirements lower limit may be about 60 SqM below which the requirements cannot be accommodated acceptably. For this range of covered area (60 SqM – 110 SqM) , for given requirements there remains no significant flexibility in values of criteria other than that for few criteria (like room layout) and all criteria start contributing to the quality of the design practically independently. This situation is designated as *"constrained covered area"*. Under this situation of constrained covered area our design should start with optimizing the most flexible and significant criteria, like room layout, which can make significant contribution to the design value.

3.2. CONCEPT OF "STANDARD USER"

For a given type of units in a mass housing (comprising individual buildings in a plotted area or individual flats in multi-storied buildings) the target families generally show a common set of expectations from their proposed residential units. But there will also be a random variation in their expectations. It is true that no design can satisfy a family fully because of many constraints. It is also true that due to the random variation in expectations the typical design cannot satisfy equally all families of the target group. Design of such typical units should, therefore, be based on common expectations of the target group so that total dissatisfactions of the group of users of the units will be minimum. This common expectation of the users can be assumed to be the expectations of an imaginary common user termed here as *Standard User*. This concept is based on the concept of Standard Eye used in the science of illumination. This helps to utilize subjective values objectively using statistical tools.

3.3. DESIGN METHOD BASED ON GENERAL SYSTEMS APPROACH

While designing a residential unit under mass housing it is assumed that outline of space available for different house units, with certain flexibility, is already decided earlier. This means that our problem here is to find an optimum design within the outline of available area. Moreover, based on condition of constrained covered area elaborated in paragraph 3.1 it is observed that the process of designing can again be split in two steps. First, optimum layout of rooms is determined and then further details are done. Our scope of study here is to study how to find the optimum layout of rooms. One may raise a question regarding acceptability of this approach of designing by first determining the outline of units, and then fitting a suitable room-layout within this and subsequently finding further details satisfying the layout. This process of designing is, however, logical based on the concept of general systems approach of designing assumed here which is elaborated below.

It is true that we live in a physical system called city (or town or village) which is a part of region. Again these physical systems may be split into different parts at different lower levels coming down to residential units where we live. This again can be split into different parts at different lower levels. The region may be considered as a super-system of the city system. Or the city may be considered as a sub-system of a region system. Similarly, a "bed room" may be considered as a sub-system of a "residential unit" or it may be considered as a system where its parts, like different activity areas within the room, are sub-systems. In general, the object for which we are interested to investigate is called *system*. Any part of it is a *sub-system*. When a combination of all parts is a *system*, this, in turn, may be a part of a bigger system called *super-system*.

If we want to design a physical system just described above we will see that quality of any object within this system-subsystem assemblage depends upon its super-system as well as its sub-system. Therefore, theoretically, one may think that a built living environment should be designed at a single go from lowest level sub-system to the highest level super-system to deal with all possible problems optimally. But this, in practice, is neither possible nor necessary.

In practice where system to be designed contains sub-systems at many lower levels and the system itself is a sub-system of a bigger system then designing is required to be done separately at different levels requiring different expertise. In general systems approach, it is assumed that weights of decisions at higher level have more value than that at lower level of the system-structure. Higher systems are designed first while lower level systems are designed at a later stage. However, in all cases of designing a system at a particular level, properties of sub-systems at lower levels and their influence on the system are taken into account. Once a system is designed making provisions for several sub-systems, any lower level sub-system of it may be considered as a system and may be taken in hand subsequently for designing. Again same process of designing is followed for the present system in hand. The process of designing a system is, therefore, a recursive process. In doing so, however, a situation may arise when a system under consideration for design is not much complicated and become manageable mathematically when mathematical optimization techniques, if available, may be adopted.

In the case of mass housing, layouts of tentative outline of different units are done first based on a very good prior knowledge about the behavior (i.e. design requirements) of housing units. Subsequently, housing units are designed within the allocated area meant for the units. In this paper also it is assumed that there is no harm in laying out the overall required areas for all units first and subsequently designing individual units within the assigned area. Housing units are chosen so small in the present paper that it is to be designed under *constrained covered area*. Under this condition, mentioned earlier, we can prepare the layout of rooms first and subsequently go on improving upon further qualities of the design based on other criteria.

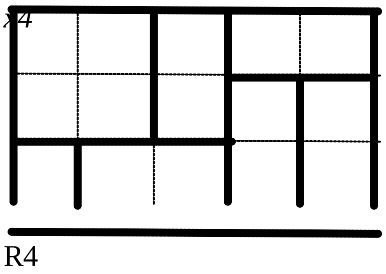
4. Synthesis Using Inputs Under Constraints

With the help of available tools and techniques of designing using the available other limited inputs we can synthesize a design with a target to fulfill explicit and implicit goals of the problem. Generally in this stage of designing many feasible solutions are generated to fulfill the goals without knowing which one is best unless technique of evaluation is used.

4.1. GENERATE ALL POSSIBLE RECTANGULAR ROOM-LAYOUTS

For this purpose let us take the concept of rectangular dissection of a rectangular area developed by Steadman (1983). With this concept we can generate all possible plans of given number of room within a given rectangular area.

Suppose we are dealing with 7 rooms. We can use a data base for all possible generic dimensionless plans. During the process of generation of all possible layouts of 7 rooms, one dimensionless plan generated is as shown in fig. 1a. If we assign different values to x1, x2,x3, … ….horizontally and y1, y2, ….. vertically under certain limiting conditions we will be able to get actual dimensioned plan (fig. 1b).



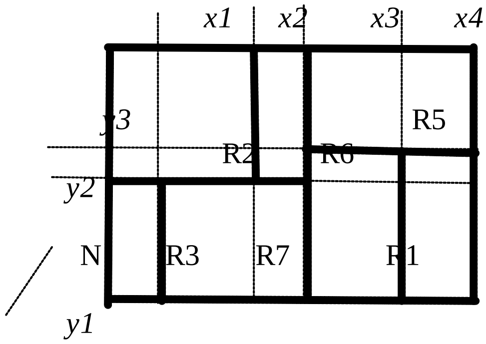


Figure 1a Dimensionless plan *Figure 1b*. One possible plan

By assigning different activity areas like bed rooms, kitchen, etc. to different rooms and placing the correct North direction we will be able to get a real plan. We can assign external and internal wall thicknesses to get the real dimensions of different rooms and over all size of the plan. We are also required to locate doors and windows to walls as per requirement.

5. Method of Evaluation Under Multiple Criteria

5.1. CHARACTERISTICS OF MULTIPLE CRITERIA

Problem of evaluation under multiple criteria is already mentioned earlier. Some characteristics related to satisfying these criteria in architecture are noted below.

(1) Satisfaction values of most of the criteria are not quantifiable because of fuzziness, subjectivity and lack of scientific investigation made so far for such criteria. Therefore, thorough scientific investigations are necessary to enable us to assign values to different criteria corresponding to different degrees of satisfaction of users attainable from a proposed design

(2) The degree of satisfaction for each criterion will have a lower acceptable limit. If a criterion represents undesirable aspect of design and have a upper limit then it can be transformed properly to make it desirable with lower limit to suit the following in-equation (3). For instance, the criterion of *cost* can be converted to *economy in cost* without any problem. If satisfaction value goes below the lower limit for any criterion then the design under consideration will not be acceptable. Each acceptable design should, therefore, satisfy lower limit of each criterion shown in a vector form below:

$$
(3)\quad \begin{pmatrix} \text{economy in cost} \\ \text{functional convenience} \\ \text{thermal comfort} \\ \text{aesthetic quality} \\ \\ \text{safety and security} \\ \text{privacy} \\ \text{stability and durability} \\ \text{sustainability} \end{pmatrix} \begin{pmatrix} L_{ec} \\ L_{fc} \\ L_{tf} \\ \\ \\ L_{ss} \\ L_{p} \\ L_{sd} \\ L_{s} \end{pmatrix} \geq \qquad L_{aq}
$$

Once this in-equation on vector of criteria is satisfied by any design we can accept the design as a *feasible solution*. When there are many such feasible solutions to a design problem then question of finding the optimum design out of all feasible solutions arises. Therefore, additional properties, as noted below, are required to be studied. There are many good developments made recently to tackle multi-criteria problems (Steuer, 1986; Radford. and Gero, 1988; Bogetoft and Pruzan,.1991) which can be used for this purpose.

(3) Any attempt to improve upon the quality (or value) with respect to any criterion by proposing alternative design may affect the quality with respect to other criteria. In many cases improvement in one criterion may lower the quality in other criterion - which means one criterion may be conflicting with the other. This also means that, in many cases, quality of one criterion cannot be improved keeping the quality of other criteria fixed or unaffected.

(4) In certain situations, however, quality of one or more criteria can be improved upon by not lowering the quality of other criteria or keeping them fixed or unaffected. In such situation there is no doubt that the modified design is really superior to the other and there will be no problem of comparing and ranking the designs. This procedure of preferring one to the other under this situation (see *fig. 2a*) is called *Pareto preference*. But if this situation is not valid and if there is variation in superiority with respect to different criteria between two designs then the task of selecting the better one will be confusing and complex (see *fig. 2b*). Any single mathematical function (like sum of weighted values) incorporating all criteria to give a single overall value for the design will not be suitable. In such models high value of one criterion may conceal the low value of other for a given design even though overall value of the design may be very high wrongly suggesting higher quality of the design.

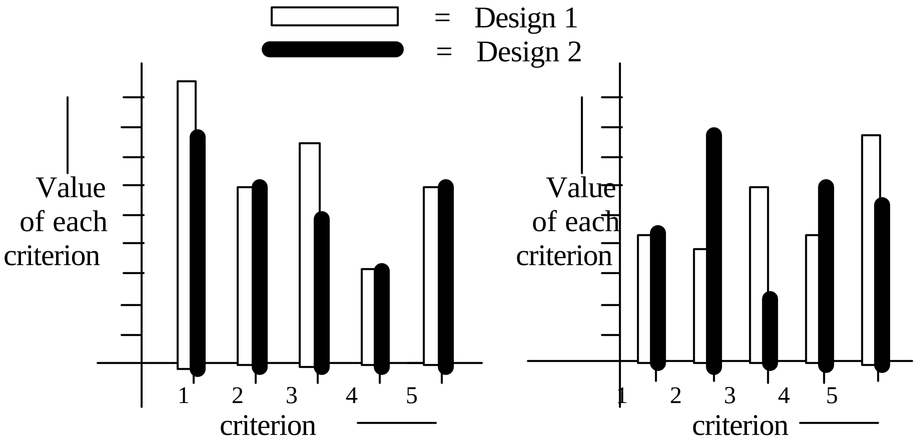


Fig. 2 a
Design of white is better than that of black (Pareto preference)

Fig.2 b
No comment can be made on which design is better

(5) If the situation is a general one (*fig. 2b*) not satisfying the conditions of Pareto preference (*fig. 2b*) mentioned above, the problem of evaluation become extremely complex. Under this situation it is generally observed that the design, which satisfies the criteria in more balanced way, is considered to be better. This idea of *degree of balanced satisfaction* of all conflicting criteria taken together is a new concept introduced by the author and is being clarified here.

5.2. CONCEPT OF BALANCED SATISFACTION

Let me explain the concept with an example. Suppose in the part plan shown in fig. 3 problem is to determine the location of the wall W (width = w M) i.e to find the distance of W from stair wall S (i.e. $l_t = ?$). Assume that overall dimension l $(= l_t + l_k + w)$ is fixed. Thickness of partition wall w is also fixed. Therefore,

$$l_t + l_k + w = l$$

or, $$l_t + l_k = l - w = c \quad \text{(constant, say, 4.2 M)} \qquad (4)$$

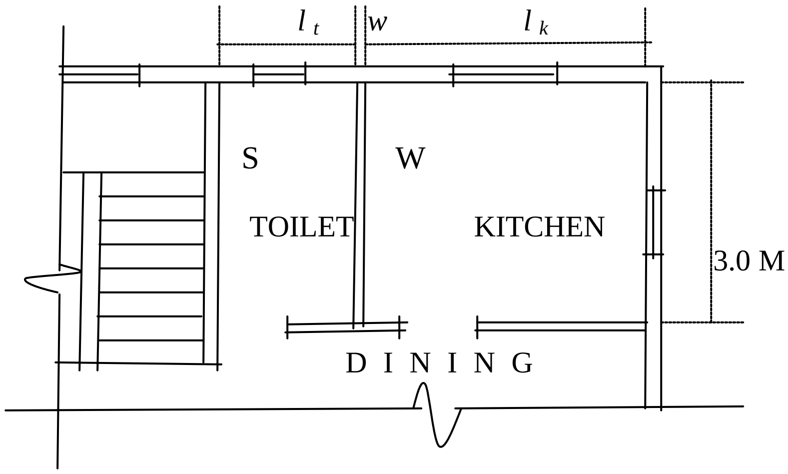
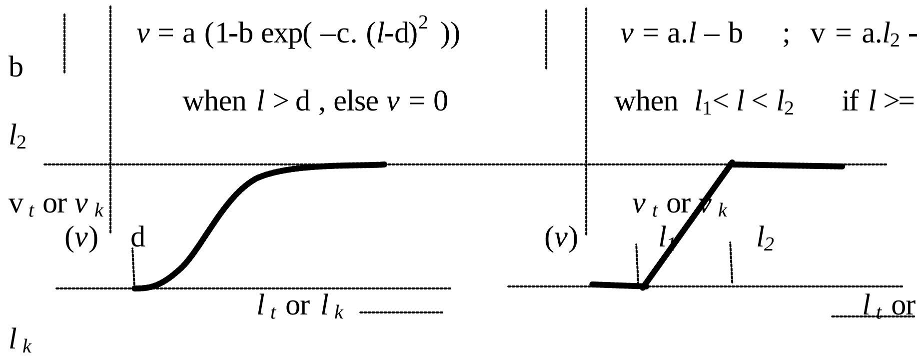


Figure 3. Part of a plan

Also assume that the values of toilet and kitchen, when dimension in other direction is 3 M, can be given by the curves v_t and v_k respectively which are functions of l_t and l_k. Curves must be monotonically increasing with the increase of l_t or l_k within a given range as shown in the following graphs (fig. 4a and b). Here nature of the curve is shown. But parameters will change depending upon the type of the room.



(a) (b)

Figure 4. Value function with respect to width of a room

If we increase l_t then l_k will decrease. Consequently v_t will increase and v_k will decease. Converse is also true. This means two values of two rooms are conflicting. If curve v_t is placed from left wall and the curve v_k is placed from the right side, both sides being placed at a fixed distance (4.2 M), then any point on the horizontal axis will indicate the location of the partition wall having l_t distance from the left wall and l_k distance from the right wall (fig.5 a and b). Thick curve shows the total value of ($v_k + v_t$) for any location of the wall. One may expect that the optimum design would be obtained when ($v_k + v_t$) has maximum value.

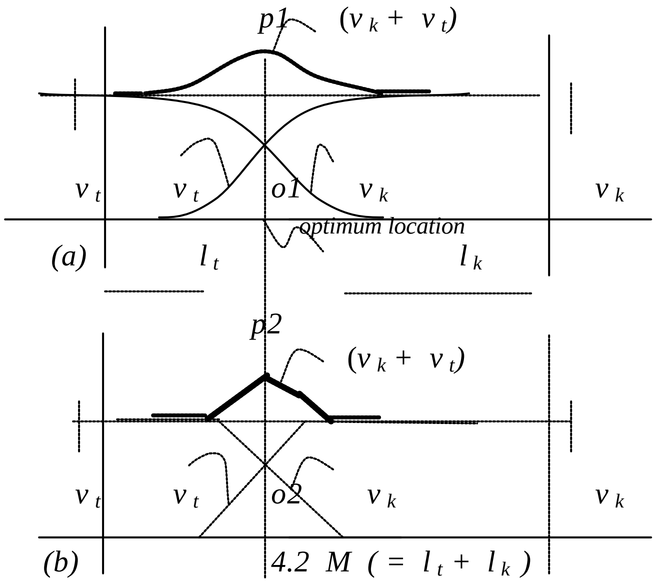
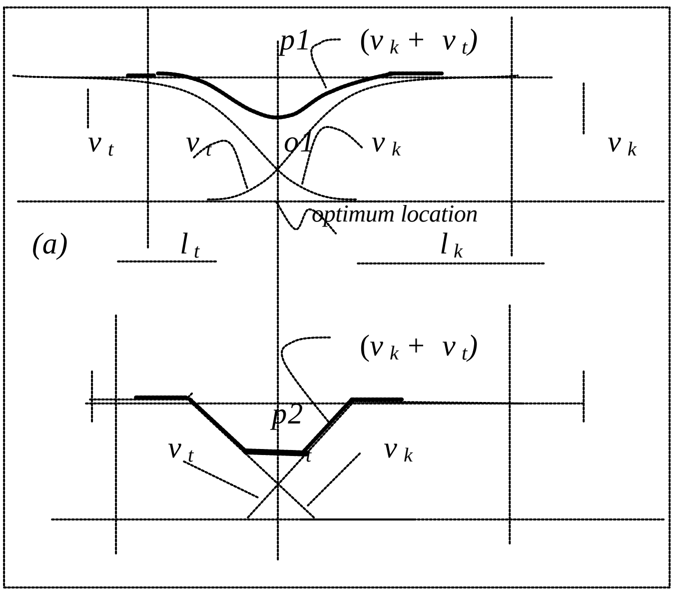


Figure 5. Alternative value functions for toilet and kitchen

But from the figure 6 it will be clear that if total length ($l_t + l_k$) is shorter then curves for v_k and v_t will be closure and instead of points p1 and p2 of the combined curve getting raised may go down. In that case there will be confusion to determine the best location of the partition wall.



v_t $o2$ v_k

(b) $4.2\ M\ (= l_t + l_k)$

Figure 6. Alternative value functions for toilet and kitchen

But if we allocate balanced distribution of satisfaction values for toilet and kitchen then point O_1 or O_2, which are intersecting points of two curves, will indicate the optimum location. Balanced distribution here means that satisfaction for both toilet and kitchen will be of same degree. Geometrically it means that at the optimum point both curves will have same height. As a result, O_1 or O_2 will be at the intersecting point of the curves (fig. 6). Advantages of this is that (i) confusion mentioned above can be avoided easily, and (ii) a simpler curve (hence, equation) like that in (b) substituting that in (a) can be used to determine optimum location of the partition wall without loss of accuracy.

Graphs or equations giving values for a criterion for different parameters can be avoided and a table of values for different parameters can also be used alternatively. Linear or any other suitable interpolation method can be used for any intermediate values.

3.3. SCALING THE VALUES

It will be clear from the above graphs or functions that the optimum or balanced value will depend upon the scale of different graphs or functions – change of scale will give different result. The reliability of values for a criterion given by a mathematical function or a table will depend upon how real situations are incorporated in the parameters of the functions or in the values in the table. Therefore, all parameters are to be derived based on the statistical surveys of real situations where desirable designs (balanced) and undesirable designs are studied. Scale is to be selected in such a way that balanced design based on mathematical functions must match with the real surveys. Then all parameters, which may change with time and space, will indicate a set of *architectural indices* of the social group for that time.

5.4. EVALUATION METHOD

5.4.1. Two Conflicting Criteria

If there are two conflicting criteria only then the equal value approach described in paragraph 5.2 can be adopted. We can adjust the design in such a way that both criteria attain the same value which will be taken as optimum design.

5.4.2. More than Two Conflicting Criteria

When there are more than two conflicting criteria selection of design based on the concept of balanced satisfaction will be more general in nature. Steps are given below.

(1) Identify a set of conflicting criteria

(2) Find respective weights of different criteria, if any.

(3) For a given design find values for different conflicting criteria. If Pareto conditions are satisfied as depicted in fig. 2a select the design which has higher values. Otherwise follow the following procedures.

(4) Find the weighted *average (m)* of values and the inverse of the weighted average of dispersion of values from m, called *proximity (p)*. m and p will form a vector $\{m, p\}$

(5) While comparing two designs (i and j) having vectors $\{m_i, p_i\}$ and $\{m_j, p_j\}$ respectively select the design which has higher vector (i.e. two elements of a vector is greater than two elements of other vector). If it is not so then select as follows. If $m_i < m_j$ then find $u_i = (m_i + 1/p_i)$ and $l_j = (m_j - 1/p_j)$. Select the design j if $l_j >= u_i$. If this is also not true then either select subjectively or by using mathematical model, derived earlier from past experience, connecting two elements of vectors.

6. Method of Selection of Optimum Room-layout

Out of many criteria to judge a design of a residential unit it was shown that under constrained covered area optimum selection become easier and layout of rooms become more significant. Moreover, it was shown also that under this type of constraint, criteria like aesthetics, economy in cost, available materials, structural suitability etc become less flexible and more or less independent of most significant criteria like room-layout. Therefore, it is assumed here that if optimum room-layout could be found then that will give the optimum design for housing unit under constrained covered area. Qualities on other criteria can be improved independently once an optimum room-layout satisfying all constraints is obtained. Following are the steps to be adopted to get the optimum layout.

6.1. STEP 1: ACCEPT LAYOUT BASED ON ADJACENCY OF ROOMS

There is little flexibility in adjacency requirements of different rooms under constrained covered area. Even if there may be some flexibility, adherence to minimum adjacency requirement is essential. Otherwise the plan will not be workable. Layouts will be selected for consideration only if minimum adjacency requirement is satisfied.

6.2. STEP 2: ASSIGN VALUES TO ALL ROOMS

Types of rooms for which value-functions or value-tables are to be determined separately are as follows: (a) Bed room (may be more than 1), (b) Sitting room, (c) Dining room, (c) Kitchen, (d) Toilet (may be more than 1), (e) Verandah or balcony (>= 0), (f) Store, passage or any other room, (g) Stair room

Under a pilot survey for this purpose some relative values are obtained for different sizes of bed rooms for middle income Bengali family in Kolkata (Calcutta) region. These values for bed room are shown in a tabular form in table 1. Top horizontal row above the bold line indicates the room length in meter (M) meant for each column. Similarly left vertical column beyond bold line indicates room width meant for each row. Contents of the remaining cells indicate relative values of rooms for the sizes of room shown by column and row values. With extensive surveys these can be modified and refined and then incorporated in a suitable mathematical model. Until then linearly interpolated values for different sizes of rooms can be used. Similar tables for other rooms can also be obtained.

TABLE 1. Relative values of different sizes of bed rooms

		2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50
2.00		2.1	2.2	2.4	2.8	3.4	4.0	4.5	4.8	4.9	5.0
2.25		2.3	2.5	2.7	3.1	3.7	4.3	4.7	4.9	5.0	5.1
2.50			2.8	3.1	3.6	4.2	4.6	5.0	5.2	5.3	5.4
2.75				3.5	4.1	4.7	5.4	5.6	5.7	5.8	5.9
3.00					4.5	5.3	5.7	5.9	6.2	6.3	6.4
3.25						5.8	6.0	6.2	6.7	6.9	7.0
3.50							7.0	7.3	7.6	7.8	7.9
3.75								7.9	8.3	8.6	8.8
4.00									8.6.	9.1	9.5
4.25										9.4	9.9
4.50											10.0

NOTE: Values outside the boarder indicate the room dimensions in Meter.
Values within dark boarder indicates room-values for all given sizes

6.3. STEP 3: ADD VALUES TO ROOMS FOR DOORS, WINDOWS AND ORIENTATION

Room values shown in table 1 are obtained for rooms having standard size of door/s at a corner and standard size of widow at the centre of one external wall. For any deviation from this basis proper modification is required. Therefore, the values may increase or decrease depending upon location and size of doors and windows. This being additive in nature may be improved upon by algebraic addition. Moreover different orientation of windows can also offer values to different rooms. These are also to be incorporated in the room values by algebraic addition.

6.4. STEP 4: GET THE OVERALL VALUE OF A ROOM-LAYOUT

Balanced value of all rooms, as mentioned above, can be taken as overall values of all rooms together instead of summing up the values of all rooms. It may be noted that here values of rooms are conflicting – if value of one room is improved value of other rooms may get reduced.

6.5. STEP 5: SELECT THE OTIMUM LAYOUT

In steps 1 to 4 we could assign value to any layout generated during the progress of generation. It is obvious that each generation, if found potential and better for retention for the time being will be stored with corresponding values. At the end of completion of generation best layout or a given number of first best layouts will be accepted for further processing.

7. Conclusion

In this paper an attempt is made to show how in reality a part of the problem of housing with small units can be dealt with using computers. Obviously tremendous research work is necessary to get a process acceptable. Even though the task is extremely difficult but once a part of a problem is solved using computer we can say at least that '*a bit of architectural knowledge is externalized*'. And in this way, bit by bit, we will be able to develop a more rational approach of designing.

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