Chapter 3

Layout design problems: systematic approaches

Edna Shaviv

3.1 Introduction

The complexity of the layout design problems known as the 'spatial allocation problems' gave rise to several approaches, which can be generally classified into two main streams. The first attempts to use the computer to generate solutions of the building layout, while in the second, computers are used only to evaluate manually generated solutions. In both classes the generation or evaluation of the layout are performed systematically.

Computer algorithms for 'spatial allocation problems' first appeared more than twenty-five years ago (Koopmans, 1957). From 1957 to 1970 over thirty different programs were developed for generating the floor plan layout automatically, as is summarized in CAP-Computer Architecture Program, Vol. 2 (Stewart et al., 1970). It seems that any architect who entered the area of CAAD felt that it was his responsibility to find a solution to this prime architectural problem. Most of the programs were developed for batch processing, and were run on a mainframe without any sophisticated input/output devices. It is interesting to mention that, because of the lack of these sophisticated input/output devices, early researchers used the approach of automatic generation of optimal or quasioptimal layout solution under given constraints.

Gradually, we find a recession and slowdown in the development of computer programs for generation of layout solutions. With the improvement of interactive input/output devices and user interfaces, the inclination today is to develop integrated systems in which the architectural solution is obtained manually by the architect and is introduced to the computer for the appraisal of the designer's layout solution (Mayer, 1977). The man-machine integrative systems could work well, but it seems that in most of the integrated systems today, and in the commercial ones in particular, there is no route to any appraisal technique of the layout problem. Without any evaluation techniques in commercial integrated systems it seems that the geometrical database exists just to create working drawings and sometimes also perspectives.

A few questions arise here: are the integrated systems more advanced than the automatically generating ones (as the people of the integrated systems generation think)? Is it correct to put one approach vis-à-vis the other? Perhaps both approaches can work together and constitute different steps in the same long design process. Each year the author exposes her CAAD students to the 'layout design problem' and they are requested to solve manually a very simple layout problem. No-one has yet succeeded in beating the computer in achieving a better layout (see Figure 3.1). The
students are fascinated by this exercise and try to find even better techniques. This raises another question as to why most of us who have dealt longer with computers than the students who are newcomers to this field gave up the computer-generating approach in favour of evaluation techniques. What were the faults in the automated generating solutions? Was the computer not powerful enough to handle large and realistic problems? Was it difficult to define the problem in terms of existing computer languages? Or are there so many different types of layout design problems that no general model can handle all of them?

Models developed by the author (Shaviv and Gali, 1974; Kalay and Shaviv 1979) which belong to the above classes, i.e. generation and evaluation, will be presented in this chapter. In these the relations between the activities in a building and their physical dimensions are dealt with very carefully. A large number of architectural constraints are treated as well. In all models the systematic design process starts with a definition of an objective function and constraints. Next, a systematic heuristic generation of the layout solution follows in one approach, while an evaluation of the design solution follows in another. Both approaches were found to have advantages and disadvantages, which will be discussed along with the models. It seems that integration of both methods might overcome some of the disadvantages and gain the advantages of both approaches.

3.2 Automatic generation of optimal or quasi-optimal building layout

3.2.1 Approaches to automatic generation of a building layout

In this chapter the complexity of the automatic generation of a building layout requires several approaches. The first attempts to create a layout that minimizes an objective function based on the circulation between any two activities (Armour and Buffa, 1963; Whitehead and Eldars, 1964; Lee and Moore, 1967; Agra and Whitehead, 1968; Shaviv and Gali, 1974). The second approach produces a layout based on constraints only (Johnson et al., 1970; Negroponte, 1970; Eastman, 1971). The third deals with automatic generation of building floor plans (Grason, 1968; Mitchell, Steadman and Liggett, 1976; Flemming, 1978; Galle, 1981).

The main thrust of the initial research was a search for an optimal or quasi-optimal building layout solution, subject to architectural constraints. Only later did researchers look only for feasible solutions that gave an answer to a given set of constraints without any objective function. This development (or retreat) can be traced to two causes: the first is the development of good interactive peripheral equipment to enable a man-machine interaction mode. So the nature of the technique changed and, instead of using the computer to reach the optimal solution, it was used in a restricted way to provide a feasible solution only. The architect could then change some constraints and find different feasible solutions until a satisfying - but not necessarily the best - solution was obtained. The second reason for the change in approach is that most algorithms for obtaining the quasi-optimal building layouts demand either a lot of computer time or such a simplifica-
tion of the real architectural problem that the problem is reduced to a trivial one. In the third approach we were trying to avoid the generation of the optimal solution on the one hand, but were not satisfied with only one feasible solution on the other. Therefore, algorithms for automatic generation of all possible solutions were developed. The idea was that the architect could later choose from all possible solutions a preferred one, and at this stage add some additional criteria for selecting a solution, such as aesthetics, ease of construction, etc. However, in the case of building layout problems, this approach is restricted to architectural problems composed of less than sixteen entities (Earl, 1977).

We note that practical, daily architectural problems, for which the layout is a difficulty, contain more than forty rooms (or activities). It is not easy to see how the solution of such a complicated problem can be found by intuition only. Next, for any set of constraints, one constraint at least can be selected as an objective function. Based on the above two premises, several models were developed by Shaviv and Shaviv and Gali (1970-1974) and will be briefly presented here.

### 3.2.2 Formulation of the models

**The objective function**

The objective function of the model is:

\[
\text{Minimize } G = \sum_{i} \sum_{j} W_{ij} d_{ij}
\]

where \( W \) is the weight between activities \( i \) and \( j \), \( d \), is a measure of the distance between these activities and the summation is carried over all pairs \( i,j \). The maximum number of activities that can be allocated is about 100, and each can have different floor area (up to 196 modular units in each activity).

The weights \( W_1 \) are the result of the quantification of the need or merit of adjacency. We searched for a scale that best expressed the difference between the indifferent, possible, preferred, very preferred, necessary and disturbing adjacency. The search was carried out by examining the effect of various scales on the final outcome and counting the number of allocations in conflict with our prescribed weights. We found that most satisfactory results were obtained when the weights describing the above affinities increased geometrically (the disturbing relation has a negative sign).

A second method of determining the weights is by weighting the value of circulation, mutual disturbance between activities and subjective criteria. One has

\[
W_{ij} = A \times P_{ij}^k N_{ij}^k F_{ij}^k + B \times M_{ij}^l N_{ij}^l + \times C_m D_m^m
\]

where \( P_{ij}^k \) = hierarchical importance of people \( k \) found in \( i \) and walking to \( j \). The hierarchy and its quantification is determined by the designer. An often-used criterion is the salary each group receives.

\( N_{ij}^k \) = number of individuals \( k \) walking from \( i \) to \( j \).

\( F_{ij}^k \) = frequency of walking of individuals \( k \) between \( i \) and \( j \).
The model enables the allocation of activities in several arbitrarily prescribed floors and the allocation of up to three staircases or elevators. The stairs need not be continuous from one level to the next. The distance between any two activities is calculated through the stairs that yield the minimal distance. The location of the stairs and their nature (continuous or not) can be decided upon a priori by the designer or can be left to the model. In the latter case the model searches for the best location from the point of view of circulation and in a way consistent with all architectural constraints.

The effect of climbing stairs a given height \( h \) compared with walking a distance \( d \) is input data, as it varies from one problem to the other. The situations in a school or a home for retired people are obviously dissimilar.

The architectural constraints
Various types of architectural constraints have been included in the model.

Constraining activities to the prescribed floors The model can constrain the allocation of given activities to specific floors (e.g. the entrance is usually assigned to the ground floor).

Requirements for prescribed orientations Certain activities may require natural light (e.g. classes in a school). This constraint is taken care of by the model’s guaranteeing their allocation to an external wall, or adjacency to an internal courtyard in the prescribed orientations. The handling of internal courtyards is dynamic and will be explained in Section 3.2.4.

Noise and other disturbances The treatment of the mutual disturbances of two activities depends on whether the designer is ready to leave
two mutually disturbing activities adjacent to each other if the total objective function is reduced or if a categorical demand 'activity A cannot be adjacent to B' is made.

In the first case the disturbances are weighted and added to the total circulation matrix. Our experience has shown that in most cases mutually disturbing activities were not adjacent to one another. However, a few exceptions were found. These cases may require specific technical solutions (acoustic walls, etc.). The cost of such solutions should be compared with the value of the objective function. When the cost is too high compared with the gain in the circulation it usually implies an underestimate of the (negative) weight attributed to mutual disturbances.

In the case of a categoric demand for separation between two activities a check is carried out to ensure that activity A is not adjacent to activity B.

### 3.2.3 Description of the automatic generation of building layout models

#### Criteria for selecting an algorithm

In considering the possible algorithm for minimizing the objective function attention should be paid to the following points:

1. The model should be able to locate many activities (about a hundred) with a different floor area each, and in few floors.
2. Efficiency of the final layout. The model should guarantee the nearest approach to the minimum of G.
3. The model must be simple and flexible to enable the easy inclusion of many architectural constraints, so that it could represent as closely as possible any real architectural layout design problem.
4. Efficiency in daily use, namely simple handling of input data, output in a convenient, ready-to-use form and low costs of operation.
5. The capability of producing a variety of alternatives. The best solution is usually not unique, and the algorithm should produce at least several alternative solutions.

#### The principles of the algorithm

The algorithm starts with an initial layout which is compared with another in which the locations of $2N$ activities are interchanged. The interchanged activities are selected randomly but consistently with various constraints. The model does not permit the formation of a layout in which any one of the constraints is violated. We distinguish between a simple interchange (SI), in which the locations of two activities are interchanged, and multiple interchanges (MI), in which $N$ pairs of activities are interchanged. The difference between the SI and MI modes of operation is the following. If an interchange of two activities does not reduce the objective function it is rejected in the SI mode. In the MI mode a new interchange of an additional pair of activities (selected randomly) is tried. If the total effect of the two interchanges is to reduce the objective function the layout is accepted and the process starts again. If no reduction of the objective function is achieved, a third pair of activities is selected (randomly) for interchange, and so on. The process continues until $N$ pairs are interchanged without reduction of the objective function. The form of the objective function is quite complicated, and there is always a finite prob-
ability to find a local minimum of G with respect to SI. In other words, it is possible to improve the layout if more than two activities are interchanged. The MI guarantee maximum scattering in the space of alternatives in the search for the absolute minimum. A limiting case of MI is the interchange of all activities, i.e. a new initial layout is tried.

Several comparison checks were performed on the efficiency of MI versus SI. Some numerical examples are shown in Figure 3.1, where a research nuclear reactor complex is illustrated. Figure 3.1 shows that the lowest value of G obtained in SI is close to the best value obtained using MI. The difference in the final results in the MI and SI is of the same order as the difference between the results obtained in SI starting with different initial guesses. Moreover, computer time increases very quickly with N. For example, the computer time on a CDC 6600 needed to reach the optimum was 2 s for the SI, 3 s for the SI + MI (N = 2) and 26 s for the MI model with N = 10.

Similar results were obtained for cases with up to ninety activities. We conclude that MI can lead out of a local minimum but the difference between a local minimum obtained by SI and the almost absolute minimum obtained by MI is usually small. We ignore the fact that the weights used in the calculation of the objective function G are hardly ever very accurate. In view of the inaccuracies in W1 one can usually ignore the differences between the results obtained in the SI and MI modes of operation.

It is of interest to rank the final solution in terms of the best and worst theoretical allocation of activities in a given grid (see Figure 3.2) This figure shows the decrease of the objective function (related to the initial value) as a function of the number of interchanges. There are two basic features to note:

1. The decrease is fast at the beginning. Consequently, there is no real need to start with a good initial guess since the number of interchanges saved is very small.
2. After a relatively small number of interchanges a plateau is reached and the solution is not improved any more. Instead a sequence of equally good different alternatives is produced. The number of different alternatives is small. After a certain number of interchanges the solution starts to oscillate between the different alternatives. The present program stores up to ten alternative solutions found. In this way several alternatives are printed at the end of each run.

Points (1) and (2) above also indicate that the random interchange technique is preferred at the first stages of convergence for the following reasons: (a) the convergence at this stage is fast; and (b) the random technique does not lead to one unique solution such as the systematic interchange technique (see Armour and Buffa, 1963) and few different alternatives can be found. On the other hand, once a plateau is reached it may be desired to resort to a systematic interchange technique (cf. below).

3.2.4 The structure of the model

The point model (PM)
The model is split into three major parts. The first treats the problem
Figure 3.1. (a) Matrix of weights, initial layouts and optimum results obtained in the point model for the example of the nuclear reactor; (b) layout solutions obtained manually by students on a CAAD course.
schematically. All activities are represented by equal-size squares placed on an orthogonal grid. This part will be called the point model (PM). The identical representation of all activities allows the mutual interchange of all activities, namely if there are no architectural constraints on any two given activities they can be interchanged though their areas may be different. The use of the PM guarantees:

(1) Insensitivity of the solution to the initial guess;
(2) Approach to absolute minimum contrary to a local minimum.
(3) Decomposition of the total activities in the building to the different floors in it, taking into consideration the shortest routes available by using different staircases each time (up to three staircases).

The total number of cells in the grid is greater or equal to the number of activities. It is possible to add an arbitrary number of dummy activities (with no relations to the real activities) should the need (or the desire) for it arise. Non-rectangular outer contours of the building may be found in this way.

**Figure 3.2.** The dependence of the objective function on the total number of interchanges for the nuclear problem. (The objective function is given in relative units)
A basic purpose of the PM is to create a good initial layout for the second step of the model in which the actual areas of each activity are taken into account (see the area model (AM) below).

**The point-area model (PAM)**
The area needed for each activity can be incorporated into the PM by allocating to every activity the proper number of fundamental units. When the assumed weight between the fundamental units of a given activity is very large, the PM algorithm will keep all fundamental units together. However, if the assumed weight between any two fundamental units is not very large compared with weights between activities, a solution may be found in which the area of some activities splits into two or more parts. The importance attached to the possible splitting of activities should be reflected in the weights. A typical numerical example is shown in Figure 3.3. The use of the PM in this way is economic only when the area of the various activities does not vary by a large factor from one activity to the other, or when all activities are represented by a small number of modular units, as shown in Figure 3.3. The effect of MI on the value of the final solution and rate of convergence changes when activities are assumed to have different areas. While SI cannot move a complete activity (if it is composed of more than one fundamental unit) and MI can, and the advantage of the MI over the SI is great. Another way to guarantee that units belonging to the same activities gather together is by using a systematic interchange technique after reaching the plateau by means of the random interchange technique.

The systematic interchange technique applied consists of two stages. In the first, fundamental units of the same activity are gathered in the same floor. The outcome may be units of the same activity scattered all over the floor. In the second phase, if required, the scattered units are merged into a single large activity (see Figure 3.4). This algorithm works well even with relatively small weights between the fundamental units. The assignment of large weights required by other methods reduces the sensitivity of the model to weights between units of different activities.

The PAM model can refer to a predetermined outer contour and we can assign a fixed location to any activity when such a situation arises.

Contrary to these features, the PAM becomes very expensive when the activities need very non-uniform areas or are represented by a great number of modular units. Moreover, it is impossible to guarantee areas with regular shapes.

**The area model (AM)**
This model considers each activity with its real required area. Each activity is assumed to reside in a rectangle. The ratio of the length to the width of each rectangle may vary during the convergence to the optimum layout but only within prescribed limits.

To save computer time (see Shaviv and Gali, 1974) the PM is used to produce an initial layout for the AM. The AM starts with a blow-up of the PM layout. The centre of every activity is placed on a very large grid and is represented by its (predetermined) rectangular area in such a way that no overlap of activities occurs. Moreover, the blow-up is made to a size which
Figure 3.3. The input and output for the nuclear reactor problem with actual areas incorporated into the PM. (a) Matrix of weights; (b) random initial layout; (c) optimal layout; (d) freehand interpretation of the computer output obtained in (c)
Figure 3.4. The systematic interchange technique. (a) Gathering together the fundamental units in the same floor; (b) merging the scattered fundamental units into a single large activity.
leaves spaces between all activities, so that internal courtyards can be added should they be desired, e.g. for natural light.

The procedure in the AM is a two-step cycle: contraction and interchange of activities. The contraction 'squeezes' the empty spaces between activities while the interchanges attempt additional permutations between activities in an analogous way to the PM. The interchanges are accompanied by trials of rotation by 90 degrees or changes in the proportions of rectangles within prescribed bounds. An interchange is rejected if the objective function is not reduced or if there is no way of fitting in the two activities with the proper rectangular areas (within the limiting proportions, including rotation by 90 degrees). Obviously an interchange must be consistent with the various constraints. The AM treats natural light and orientation, and corridors and determines the module of the building as follows:

**Natural light and orientation** The handling of natural light and required orientation is dynamic. Suppose a given activity which requires natural light and a northern orientation is located on a northern wall. When the model tries to interchange it with another activity the following checks are made as well as all other constraints: (1) if the new location is on a northern external wall and (2) if (1) is not satisfied is there enough space to add an internal courtyard consistent with light conditions? If the answer is yes the interchange is performed and an internal courtyard is added to the building. Analogously, when such an activity is moved from inside the building to an external wall the internal courtyard is deleted. Since the addition of an internal courtyard increases the circulation the effect of the model is to shift such activities to the outer boundary of the building and cancel internal courtyards if possible.

**Corridors** The corridors in the building can be determined a priori and activities are then translated along them. Obviously, the space for possible solutions is drastically diminished and the quality of the final layout depends on the particular system of corridors. We feel, however, that dictating the corridor system implies an a priori imposition of architectural concepts. We prefer therefore to ignore the problem of passes at the beginning and increase the area of every activity to compensate for passing areas. The final layout is considered as a general scheme of the building into which passes must be added. At the moment the passes are added manually. We consider the extension of the model to include a search for an optimal passing system.

**Determination of the module of the building** A special subroutine allows the determination of a module for a building. This is chosen from a list of possible values consistent with furniture, structural materials or Ministry of Housing regulations. The number of modules in the length and width of the area of each activity is found according to a mimum absolute deviation from its required area and within the allowed proportion. The best module s chosen according to minimum deviation from the total area of the building. The output contains the dimensions of all areas. As the module is found prior to the optimization the AM is allowed to modify an
area by a given integer number of modular units and in the range of the allowed proportion.

Contrary to the PM, the AM cannot guarantee at present the identity of the outer contour of all floors. This must be brought about manually, as is shown in the case-study (see Figure 3.5).

The most important advantage of the AM is that it is a cheap solution in the case of large variations in the areas of the various activities. We have made successful runs with 84 activities composed of up to 196 modular
units with areas varying by a factor of 50. The running time of the three-floor scheme presented in Figure 3.5 is 193.26 s (on an IBM 370/168). Next, while there is no need to define a priori the grid of the building there is still the option of preserving the shape of the rectangle that contains the building, as may sometimes be desired.

3.2.5 Critique of the models

The algorithm of the AM model combined with the schematic phase of the PM model resembles the architect's frequent attempts to obtain the layout of a floor plan. At the beginning he tries to understand relations between the activities by using techniques such as the bubble diagram. Next, he adds the area and tries to relocate the activities by playing around with pieces of paper with reduced areas. This is done faster by the computer. Furthermore, several alternatives can be checked. Therefore the solution obtained should in principle be equal to or better than those found manually.

The random interchange technique covers the entire area of possible layout solutions, and therefore it is not a path-oriented method like the systematic interchange technique. This guarantees that different suboptimum solutions are found, i.e. the creation of different alternative design layouts to the same problem. As a consequence, a better suboptimum can also be achieved, as is the case with the systematic interchange technique.

The output obtained by the computer is not the final layout. It is only a good hierarchical decomposition of the complete layout into the desired number of floors. Also it can serve as a very advanced schematic design of each floor. From this stage the architect can go on and design the building manually. The use of this model enables him to start with a good functional layout and concentrate on the design.

However, it seems that at this stage of the design process the architect should move on to the second approach, i.e. evaluation and appraisal techniques. Any manually created design in which a different contour of the building or different corridors are assumed will influence the objective function. Also it is possible at this stage to include additional design criteria and appraisal programs. This can include an accurate determination of the thermal performance of the building, its acoustic quality, its structural behaviour and its cost. There is no contradiction between the two approaches mentioned above. On the contrary, they complement each other to form a continuous design process.

3.3 Evaluation of a building layout design

3.3.1 Introduction

The evaluation and appraisal approach was first developed in the early 1970s, and the motivation for such an approach was the conviction that human creativity was superior to that of machines in creating design solutions (Mayer, 1970). The appearance of good interactive graphical equipment for online machine control was also one of the reasons for
developing this approach. In this way the architect could evaluate his design proposal very easily.

During 1978-1979 we developed in the Technion a model for evaluating standard dwelling units designed for the Ministry of Housing in Israel (Kalay and Shaviv, 1979). Although we did not have any graphical input device at that time and worked in the batch mode, we decided to use an evaluative technique for the layout design problem. Our main reason for preferring this method was the consideration that more design parameters could be evaluated and in a more sensitive way. We also believed that not only quantitative appraisals could be performed (for example, the calculation of the distances between the activities) but qualitative evaluations as well. This included the evaluation of the character of the connection, the privacy needed and the flexibility of the dwelling unit.

3.3.2 The structure and description of the model

The model consists of four different parts:

(1) The analysis and evaluation of activities layout in a dwelling unit; (2) The evaluation of the dimensions of rooms;
(3) Evaluation of the flexibility of the dwelling unit; and
(4) The appraisal of the environmental behaviour (this will not be discussed in this chapter).

Evaluation of activities layout in a dwelling unit

The particular properties of dwelling units and their small dimensions give rise to a new set of values different from those of complex buildings with a large number of occupants and activities. For example, the distance between the locations of various activities is affected primarily by the mutual spatial relations between them and only minimally by the Euclidian distance (we ignore the fact that the Euclidian distance in a dwelling unit is poorly defined). Moreover, it is practically impossible to define the 'strength' of a relation between two activities which will express in some continuous and monotonic way the improvement in the layout due to a continuous change in the distance between activities. Consequently, the evaluation of a dwelling unit layout cannot be performed by calculating the distance between the locations of activities and a definition of an objective function of the general form

\[ G = \min \sum_i \sum_j W_{ij} d_{ij} \]

where \( W,1 \) is the strength of the relation between activities \( i \) and \( j \) and \( d_{ij} \) is the distance between them, leads nowhere.

Let us elaborate the problem a little more the light of the objective function philosophy. A prime factor in the mutual relation between two activities in a dwelling unit is the degree of privacy required. Privacy is important on a personal as well as on a family level. The physical distance \( (d, l) \) between the locations of activities has secondary importance, though it cannot be ignored. Consequently, the connection \( (W11) \) between two activities \( A \) and \( B \) is affected by the following factors:
(1) The privacy of activity A;
(2) The privacy of activity B;
(3) The affinity between activities A and B; and
(4) The mutual disturbances between the activities A and B.

In view of the various factors affecting connectivity between units we propose to overcome the above difficulties of defining the distance between the two activities \((d_{ij})\) by using a discrete space of finite dimensions without any metric in it. The mutual spatial relations between the locations of activities is projected onto this space. The internal structure of a connection between activities is analysed and defined directly in the discrete space of mutual spatial relations. We call this the MSR space.

By limiting the model to one floor (this is the regular dwelling unit in Israel) we define eight types of relations in the MSR space as follows:

(1) Both activities in the same space;
(2) The activities in adjacent spaces, with a partial partition;
(3) The activities in adjacent spaces, with a connecting door;
(4) The activities in spaces connected through a private corridor;
(5) The activities in spaces connected through an open corridor;
(6) The activities in spaces connected through a space containing semipublic activities; and
(7) The activities in remote spaces.

The problem we face now is how to define a \(W_i\) matrix in the MSR space. The non-existence of a metric in the MSR space prevents the arrangement of a simple quality ladder in which the elements of the MSR space are arranged according to a monotonic quality function. To be more specific, given two general activities \(i\) and \(j\), it is impossible to claim that when the two activities are located in a relation corresponding to element 1 in the MSR space it is always superior to a situation in which they are located in a relation corresponding to element 2, etc. In other words, due to the particular nature of the MSR space and the structure of a connection in a dwelling unit, it is impossible to arrange the elements of the MSR space in a monotonic order of quality. One possible way to make progress is to take two activities, say \(i\) and \(j\), and construct an eight-dimensional quality vector, the elements of which are the degrees of quality of each of the eight elements of the MSR space.

As mentioned above, the connections between activities are described in terms of the privacy, affinity and mutual disturbance between the two activities. Let us define a four-dimensional vector, the components of which are: the privacy required by the first activity, the privacy required by the second activity, the affinity between the activities and the mutual disturbance. There are altogether 34 different vectors. To each of these four-dimensional vectors a quality vector can be associated. Once the correspondence table between the four-dimensional vector defined in terms of the connections and the quality vectors defined in terms of the MSR elements is accomplished the problem is solved because, assuming that two activities are given, the first step is to find the corresponding four-dimensional vector. The quality vector is found from the table of fourdimensional correspondence between the four-dimensional and eight-dimensional vectors.
dimensional vectors, (see Figure 3.6). The comparison with the configuration in the real layout now provides a measure of the quality of the layout.

We found in building this correspondence table that four degrees of quality are sufficient for describing the situation in a dwelling unit. Consequently, we define the following categories of qualities or relations: A - best, B - good, C - possible and D - bad. A further breakdown is not meaningful in view of the general accuracy expected in the problem.

![Table Image]

Figure 3.6. The four-dimensional – eight-dimensional vectors correspondence between the components of a connection and elements in the MRS space
The steps in the evaluation of the activities layout in a dwelling unit are as follows:

1. The tables that provide the required affinity between activities, their mutual disturbances and degree of privacy of each activity are defined for the relevant population under consideration and are given as input.
2. The four-dimensional and eight-dimensional correspondence vector is given as input.
3. The floor layouts, including the exact placing of doors and the location of activities, are given as input.
4. A transformation of the physical layout into a layout in the MSR space is performed by the program and the special relations between the activities are found by determining the relative position of the two activities and the existence of walls, opening or a third space between them. In such a case the character of the activity in this space is also determined.

The model takes into account the possible existence of several openings in each space and several routes between the activities. It searches for the best spatial relation on the basis of the best relations as defined in the correspondence table. The assumption is that the dweller knows the best solution. The corresponding elements of the MSR are marked in Figure 3.7 by numbers.

5. Use the correspondence table to evaluate the quality of the mutual connections that was found in the given alternative (marked in Figure 3.7 by letters).

6. Summarize the agreements and deviations found in the previous step by counting the first grade, second grade, etc. connections. Clearly, the best layout is the one in which all connections are of the first grade. However, such cases are rare.

In comparing the two layouts we face the problem that not all activities have the same importance, and consequently a poor connection between activities \( i \) and \( j \) may not be considered as important as a poor connection between \( i2 \) and \( j2 \). We have therefore defined a scale of the importance of activities. This is based on factoring the activities to two categories -essential and non-essential activities. Each category is divided again into dominant and not-dominant activities. An activity is essential if it must exist in the dwelling unit. A dominant activity is one that dictates the character of the space in which it is located.

The two scales used in this model (for the grade of the quality of the connection and for the importance of the activity) depend considerably on the user of the dwelling unit and should be given correspondingly. Finally, a comparison between alternatives is performed by calculating an index according to:

\[
\text{Index} = \frac{\sum W(k_{ij}) \cdot I_i \cdot I_j}{\sum W(A) \cdot I_i \cdot I_j}
\]

where \( k_{ij} \) is the quality of the connection between activities \( i \) and \( j \), \( W(k_{ij}) \) is the weight given to quality \( k_{ij} \), \( W(A) \) is the weight given to the best quality \( A \) and \( I_i \) and \( I_j \) are the importance of activities \( i \) and \( j \) (see Figure 3.7).
Figure 3.7. Comparisons between the required and the realized configurations in the MSRspace
Evaluation of the dimensions of the rooms in a dwelling unit

The evaluations of the dimensions is based on the area analysis of the physical spaces (i.e. rooms) containing the activities in the dwelling. The area needed for such a space is a function of the number of the activities contained in it as well as their character and size, which depend on the size of the family and standard of living. The same room layout can contain different activities. Recall that furniture can be moved from one room to another, and hence each possible arrangement is considered as a different layout alternative. This fact is important for the evaluation of the flexibility of the apartment to fit different family sizes, as will be explained in the next sub-section. On the other hand, the dimensions of each room are maintained. Standard buildings in Israel are built from heavy materials and therefore partitions inside dwelling units cannot easily be moved.

We consider for each activity the nuclear area, which is the physical area occupied by furniture, and the field area, which is the area used as paths. The nuclear area should not overlap any other nuclear or field areas. However, there can be an overlap in the field areas. We allow different overlapping according to the category of the activity - essential or nonessential and dominant or not. According to these two categories we allow no overlapping in the fields of dominant activities, and 40 per cent or 80 per cent overlapping in the fields of essential or non-essential and nondominant activities, respectively. Following these rules, we can calculate the required room area \((x)\) according to the activities contained in it. However, we found that the real room areas designed in different dwelling units \((y)\) differ from the calculated ones. The area \(y\) was found to be much larger than the calculated one, especially in small rooms. The reason for these differences are psychological, and follow from the inconvenience of small crowded rooms. We therefore checked, the correlation between the area of each room in 18 different architectural plans and the calculated area \(x\) according to the activities in every room. A linear relation was found to exist between the real area \(y\) and the calculated one \(x\), i.e. \(y = Ax + B\), where \(A\) and \(B\) are given in Figure 3.8 (a). Note the correlation coefficient \(R\) is very high, supporting the validity of the linear relation. One can notice also from Figure 3.8(a) that the parameter \(B\) is relatively large in rooms that include many passing areas, like living rooms. Ti situation is reversed in rooms that include many activities and no passing area, like the kitchen. Here \(B\) is very small compared with \(Ax\) and \(A\) is close to 1, which means that \(y\) is almost equal \(x\).

The steps for evaluating the area of each room are as follows:

1. Give a list of required areas and minimum width for each activity according to the size of the family and the three standards of living.
2. Determine the area and width of each room in the suggested layout.
3. Determine the required area \(y\) and the minimum width of the room according to the activities contained in the room.
4. Compare the existing area and width with the required one according to the three standards of living and find the absolute and relative differences.
5. Summarize the difference between the designed and areas required according to the standard of living (see Figure 3.8(b)).
Figure 3.8. (a) Physical space area-correlation parameters; (b) the evaluation of the dimensions of the rooms in a dwelling unit.
If the area analysis shows that the area of the room is smaller than the required one, and it includes non-essential and non-dominant activities, these activities are removed from the room. The area is reevaluated for the remaining activities. This procedure is required because the residents of this dwelling unit will find out how to use their apartment most effectively. The implication is that the architect's efforts to enrich the design alternative by addition of more activities yields a non-realizable solution.

The last check performed by the model is part of an attempt to include in the evaluation model some generative technique as a second stage. The model can now be extended in different directions: either try to move the activity to another room, where there is a place for it, or add the minimum required missing area to include this activity in the proposed room.

In principle, once the weak points of the layout are found by an evaluation technique, this information can serve as input to a second stage, where an improved layout is generated automatically.

**Evaluation of the flexibility of a dwelling unit**

The model evaluates the degree of adaptability of the dwelling unit to different family profiles and to different possibilities of continuous changes in the family structure during its life-cycle. The assumption is that each stage in the family life-cycle has certain special physical requirements in terms of number of activities and the spatial standards required by them, and the model determines the degree of adaptability of the dwelling to each of these requirements.

The determination of the requirements may change with the target population. In this model we assume a family of one to five members. More than 90 per cent of the families in Israel have less than six members. No distinction between sexes was made. The restriction leads to 17 different family profiles (see Figure 3.9(a)). The physical requirements of each profile are listed, i.e. the required activities and their size (as defined by three categories: small, medium, and large). Next, the combinatorial tree of the different possible life-cycles is found. A life-cycle is defined by a string of family profiles during its life. For example, one possibility can be: a couple, a couple with a baby, with one child and then with one adult child. After the child leaves home, we again get a family of two and one. Such a life-cycle will have to satisfy the demands of the following family profiles: 2, 3, 4, 7, 1 (see Figure 3.91(a)). If a dwelling unit can fit only profiles 1, 2, 3 and 4 (i.e. it does not fit a couple with one adult child), we do not consider this dwelling unit as one that fits the above life-cycle. The combinatorial tree of a family of one to five persons contains 620 different life-cycles.

The steps of the evaluation of the flexibility in the layout are:

1. Provide as input the physical requirements of the 17 different family profiles and the combinatorial tree of a family life-cycles.
2. For a given dwelling layout provide the different alternatives for locating the activities.
3. Each layout alternative is checked for the number of family profiles it satisfies (see Figure 3.9(b)).
Figure 3.9. (a) Matrix of family profiles. (b) Flexibility matrix of a given design alternative. The table lists the family profiles the present alternative fits and the total agreement to the dimension and connection requirements. (c) A summary of all family profiles supported by any design alternative and the total number of life cycles.
All family profiles supported by any given alternative are found (see Figure 3.9(c)).

The different life-cycles and all of the above family profiles fit, are checked and summarized (see Figure 3.9(c)).

3.3.3 Critique of the model

The model allows a very detailed and sensitive evaluation of the connection between the activities, the dimensions of each room and the flexibility of the dwelling unit and requires many data for this evaluation. These data fit only one kind of target population and therefore should change for a different target population. The model can analyse the sensitivity of the layout solution to the location of doors and openings and their exact dimensions. It can also show the addition of an area to the dwelling unit and help in achieving fitness to different family profiles and different lifecycles. This is important when dwelling units are designed for a target population. Maximum flexibility is desired in this case to allow for design for a special family.

The second stage, the attempt to improve the suggested alternative design, is missing, and we suggest that efforts be made to include this.

3.4 Conclusions

The models presented in this chapter were devised to deal with the complexity of layout design problems in a systematic way, either by using an evaluation or an automatic generation technique. In both cases it was found that these two techniques should not be separated, but should act as one continuous design process. The order of using these two techniques should be as follows:

1. Automatic generation of alternative design solutions. This can be done according to the most important requirements that can be included in an objective function. The rest of the requirements can be treated as constraints.

2. Evaluation and appraisal of automatic (and not manually) generated design alternatives. This stage will include a very detailed and sensitive evaluation of each requirement.

3. Find the 'Achilles' heel' by using the evaluation technique in stage (2) and generate automatically new and better design alternatives. From this stage we can return to stage (2) and then back to (3) until we find in stage (2) that the suggested design solution fits best all the requirements.

Using this proposed approach we can reveal, by automatic generation techniques, new and better solutions than we could achieve manually in the traditional way, thus best exploiting the computer to our benefit.
References


