COMPUTERIZED DESIGN OF BUILDINGS

COMPUTERIZED DESIGN OF SMALL BUILDINGS USING MODULAR CONSTRUCTION

by

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SCOPE AND CONTENTS:

A new prefabrication building system using modular construction is proposed.

The existing housing systems, the requirements of both the housebuilding system and the dwelling house are discussed. The effect of innovation in building and the use of standardization, coordination and preferred dimensions are described.

A study of the space allocation problem; its definition, importance, and solving techniques is presented.

The computerization of plans based on the proposed system of building is achieved through the use of the user oriented program developed in this thesis. It designs the optimum plan configuration given the user requirements and constraints.

PREFACE

This thesis contains a proposal for a new prefabrication housebuilding system, which, it is believed, satisfies many of the requirements of an ideal housing system and combines many of the features of existing systems. The important modular concept is used in planning.

The building trends in North America and the existing housing systems are reviewed, requirements of both the housebuilding system and the dwelling house are discussed, the effect of innovation in building is explained, and the use of standardization, coordination and preferred dimensions is described.

A study of the space allocation problem; its definition, importance, and solving techniques is presented.

The computerization of house plan based on the proposed system of housebuilding is achieved through the use of the program developed in this thesis, which is a user oriented program that designs the optimum house configuration, given the user constraints such as the room areas and exposure directions.

Although the program is used here in designing houses, it is general in nature and capable of producing any plan layout for any kind of buildings; industrial, commercial, institutional, applying either the relationship and neighbouring concept or the circulation cost concept as a decision criterion.

ACKNOWLEDGEMENT

The author wishes to express her sincere appreciation and indebtedness to her supervisor, Professor James N. Siddall, for his valuable advice and helpful suggestions. Chapter III in this thesis is based on his report on "A New System of Housebuilding". His constant attention, continuous guidance, interest and criticism were most helpful, both in carrying out the study, and in making it a really valuable learning experience for the author.

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CHAPTER I

INTRODUCTION

1.1 THE THESIS OBJECTIVES:

This thesis will illustrate one way in which the architectural designer can use technology as a physical part of his daily practice. Through technology the architect can eliminate many of the time consuming tasks of the building design process while achieving far better results.

It is the task of this study to explore the potential of applying the space allocation techniques to the architectural profession and present a proposal for using one of them in designing a house plan, utilizing a new prefabrication house building system. A vivid representation of the user desire in the form of a block layout is produced using the developed computer program which allocates the resources of computer time and space in as efficient a way as possible to produce a high likelihood of coming up with an optimum solution.

In view of the fact that most basic architectural decisions are mathematical in nature and often full of repetitive effort, the computer can be an invaluable aid to the architect in these areas of decision-making. Then, the ultimate objective is the mechanization of all those parts of planning tasks that are easily done by computer and not easily or willingly done by the architect.

1.2 DESIGN AND THEORY OF VALUE:

It is possible to discuss what is meant by "design" in detail, but for the purpose of this thesis, a statement by Herbert A. Simon speaking about the science of design provides an appropriate perspective: "Historically and traditionally, it has been the task of the science disciplines to teach about natural things, how they are and how they work. It has been the task of engineering schools to teach about artificial things, how to make artifacts that have desired properties; how to design. Engineers are not the only professional designers. Everyone designs who devises courses of action aimed at changing existing situations into preferred ones." (21)*.

The concept of value is perhaps the most fundamental of all components of the design. At this point I wish to quote some of the expressions of Siddall, J.N. speaking about the theory of value in design: "Value may be defined as that which satisfies desire. It may be considered as inherent property of an engineering design. Obviously then the designer must design his product so that it generates maximum value for the user. By some means, usually intuitively, the designer assigns a value in the philosophical sense to each of the design variables, this value is a measure of the satisfaction that the user will derive from the product and each variable makes some contribution to the overall satisfaction provided. The designer must then, select the best combination of engineering elements to synthesize a design, and then must juggle the quantities assigned to variables in order to maximize the total value potential. He will then have the best possible design." (10).

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* Numbers in brackets designate references in the bibliography.

There are many categories of value. Utility value is the appreciation of usefulness of an object and aesthetic value is the appreciation of beauty and style. Utility and optimization are intimately related and cannot be discussed independently; utility is the quantity which we maximize in optimization. Aesthetic value is of particular significance in design; beauty of a design or a design concept is an intuitive measure of how well a design is optimized. Utility and aesthetic are dependent design variables which means that they are quantities that the designer works with but cannot directly allot values to.

The value is a measure of how well the design satisfies the desires of the user, and is a function of the remaining dependent design variables. In the present state of the art, a large part of the design process is still intuitive, using aesthetics as the important criterion. But there is considerable scope for the analytical optimization of elements, and all designs should be examined for the cost feasibility of doing analytical optimization.

1.3 THE NEED FOR THIS STUDY:

Todays practicing architect is under great pressure to complete his design work in the least possible time. An architect must not only speed up the design process, but also he must deal with increasingly complex and varied design parameters, consider factors on a more rational basis than was previously considered, and communicate design information accurately to his client and other members of the design team.

The architect usually designs buildings by the intuitive method, in other words, design by experience, knowledge, and tradition. The architect is ever mindful of structural, functional, and aesthetic requirements of the project with which he is concerned, but the burden of maintaining the overall idea of the building's concept, while developing the smallest details of the design, is becoming increasingly heavy. As a result, the architects and engineers have devised many tools to ease their task, such as construction catalogues, product catalogues, and many other texts which provide the designer with listing of material and product specifications, standardized space requirements for different purposes, and information about colours, sizes, and installation methods. These devices are aids which enhance and insure the success of the architect in the design process. The services available through systems analysis in the area of space allocation are also aids to the architect in fulfilling his obligation to produce good functional buildings. Just as the architect cannot keep in mind the many materials and products available for his use, neither can he be expected to analyze and remember all of the possible solutions for providing a good functional layout.

This shows the need for new methods of design which decrease the designer's effort while achieving better results.

1.4 THE GENERAL APPROACH AND MAIN TOPICS:

A study of house building is presented in Chapter II. The building trends in North America and the existing housing systems are reviewed, the requirements of both the housebuilding system and the dwelling house are discussed, the effect of innovation in building is explained, and the use of standardization, coordination and preferred dimensions is described.

The new proposed prefabrication housebuilding system is described in Chapter III. Chapter IV is devoted to the space allocation problem and the past effort for solving it.

The mechanics, methodology and capabilities of the developed computer program is elaborated upon in Chapter V.

Several examples are presented in Chapter VI to illustrate the use of the derived computer program, the amount of adjustment needed to transform the produced block layout into an architectural layout. A final floor plan with details such as stairs, doors, windows, closets, cupboards, and shelves is provided for each example to show the flexibility of the proposed housebuilding system.

Final conclusions and indications for possible further development are discussed in Chapter VII.

CHAPTER II

A STUDY OF HOUSE BUILDING

2.1 REQUIREMENTS OF HOUSEBUILDING SYSTEM:

A housing system has two major purposes:

(a) To provide relatively few standard components that can be assembled on the site without cutting or fitting, thus reducing labour costs.

(b) To provide components that use material more efficiently and thus permit saving in raw material.

A housing system should satisfy the following requirements:

(a) It should have basic standard components that can be easily assembled in many combinations of floor plan, colour, material, texture, etc.

(b) It should cost less for both material and labour, relative to conventional housing.

(c) It should apply standardization to mechanical as well as structural components of the house.

(d) Necessary site work, such as foundations and basements should be minimized.

(e) It must not be too difficult or expensive to transport.

(f) It should permit easy addition of custom features, such as fireplace, special built-in features, basements, etc.

(g) It should be fairly conventional looking.

(h) It must have a strength and durability equal to, or better, than conventional housing.

2.2 EXISTING HOUSING SYSTEMS:

There are four existing housing systems known to the writer:

(a) The most primitive system used, conventional construction and merely precuts the material to correct size for site assembly without additional fitting. The material units are still small and very little material is saved. Flexibility is poor; since the precut pieces cannot be used in more than one house design.

(b) Another primitive system simply assembles complete buildings in the factory and carries them bodily to the site. It is limited to small sizes and a very few designs.

(c) Conventional or semi-conventional construction is also prefabricated by building sections of a few stock plans in the factory and assembling sections of wall, roof, etc. at the site. This system again has serious limitations on flexibility and transportation.

(d) The most radical approach provides new standard building components in the form of wall, roof, and floor panels. These panels are factory built and attached together at the site. All panels are usually structural. The system is based on the modular concept described in detail later in this chapter. Such a scheme satisfies most of the purposes of prefabrication but has not received public acceptance. The cost saving has not been substantial enough to overcome public prejudice. This resistance to panel housing is probably due to unconventional appearance and mistrust of a radically new method of building.

There are few other houses outside these classifications which have had limited success. The Fuller house was a small, round, center column supported, all metal building of quite radical design. Variations of monolithic cast concrete houses, using prefabricated forms are occasionally attempted. A recent proposal is the adaptation of mobile home units. These are combined in units to make up a house.

2.3 BUILDING TRENDS IN NORTH AMERICA:

Due to the increasing costs of building, partly because of the increasing complexity of buildings as well as rising unit costs, economies are continually being sought in the following ways:

(a) Minimizing and simplifying site operation, and a drastic reduction in the use of hand labour for the elaborate finishing of buildings.

(b) Increasing the use of materials that can be prepared with the aid of factory mechanization for direct use on the job.

(c) Providing a maximum repetition.

What is prefabrication? A sophisticated definition of prefabrication or industrially-made building components has been formulated by the Second Seminar on the Building Industry of the United Nations Economic Commission for Europe in May 1967 as follows:

> "The design of industrially-made building components is a complex process, the aim of which is to attain an overall optimum as regards functional efficiency, flexibility in use, productivity and economy of manufacture, assembly and maintenance combined with an aesthetically attractive appearance." (25).

The swing in favour of prefabrication depends mainly on the amount of repetition and the degree of standardization involved. Prefabrication is cheaper when the saving due to the elimination of the in-site work exceeds the combined cost of fabrication, transport from the factory, and the cost of erection.

2.4 THE EFFECT OF INNOVATION IN BUILDING:

A basic underlying concept is that any proposed system must be evolutionarily compatible with the currently used housebuilding system. For this to be true the innovative jump cannot be so great that the whole house construction industry is dislocated. Excellent designs in the past have failed because of this.

The craftsman is bound by years of training to invest his life in the industry and can rarely escape the consequences of being irrevocably committed at an early age. It must be clear that anything that threatens the security of the worker is bound to arouse his suspicion; if innovation does not do that, then they welcome it. They will welcome new techniques and mechanization which do not displace the traditional crafts, but do displace sheer muscular effort, especially that of unskilled labour.

Labour relations remain unaffected by the institution of new techniques provided that no changes are proposed that adversely affect the workers' economic standard of life.

Indeed the best way of ensuring the success of a new technique is for it to be seen as a means of securing an improvement of wages and conditions. It is clear that from the employers' point of view an innovation will not be made if it is not counted as profitable.

Thus, innovation that ignores all considerations of historical development, aesthetic, economic and social, is certain to prove an element of disruption, whereas with the proper approach it can bring about constructive changes and higher standards.

In view of the above, it is not surprising that the influence of the more powerful building trades unions has been successful, especially in the U.S.A., in preventing further advance in the use of many prefabricated groups of components in building jobs.

2.5 DWELLING HOUSE REQUIREMENTS:

Until the last century, the main concern about buildings was their stability, that is, their resistance to the effects of gravity, dead and live loads, their durability, resistance to natural weather conditions, and the protection they provided against rain and wind.

2.5.1 Enumeration of Functional Requirements

I: A house must provide its occupier with a healthy environment, favourable to rest, in spite of troublesome external factors, whether natural or otherwise, and also provide certain amenities. The corresponding requirements are of two kinds; physiological and psychological.

A. Physiological Requirements:

1. Sound levels.
2. Thermal levels and physical state of air and walls.
   - Draughts.
   - Uniform temperature.
   - Dryness of walls.
3. Level of purity of air.
   - Dust
   - Gases
   - Micro-organisms.
   - Odours.

4. Level of lighting (natural and artificial) and quality of light and darkness required for sleep.

5. Radiation levels.

6. Ease of access from public highways (by ramps, stairs or lifts in safe conditions).

B. Psychological Requirements:

1. Space.

- Internal space of rooms must be sufficient not only to be able to sit in and move about, but it is also necessary to have a certain amount of proportionality.
- External space is important to those who spend most of their days indoors (in offices, factories, etc.).

2. Aesthetic level.

- Colour.
- Smoothness and grain of surfaces.
- Trueness of lines and angles.

3. Safety level.

- Safety against collapse is an absolute requirement.
- A dwelling must protect its occupants and their possessions against harmful human actions and dangerous or undesirable animal intrusion.
- Fire protection arrangements and escape ways.

II: The dwelling must offer adequate facilities for family life.

a. Space.

b. Services.

- Water (cold and hot).
- Electricity.
- Drains and garbage disposal.
- Telecommunications.
- Nailability on at least one wall of the living rooms.

III. The above requirements should remain satisfied for a normal period of time, with normal usage, and taking into account normal destructive factors, and assuming normal maintenance.

2.6 COORDINATES AND STANDARDIZATION:

The design and selection of components to form a "kit of parts" that can be assembled in many different ways can only be achieved by applying the principles of dimensional coordination.

2.6.1 Standardization

Maximum use is made of standard repetitive components, by joint consultation between the building system designer, manufacturer and builders.

It is not always possible to obtain complete standardization of the dimensions of units, however, the cross-sections can be standardized having a variable length, but with a strictly defined range of preferred dimensions described in detail below.

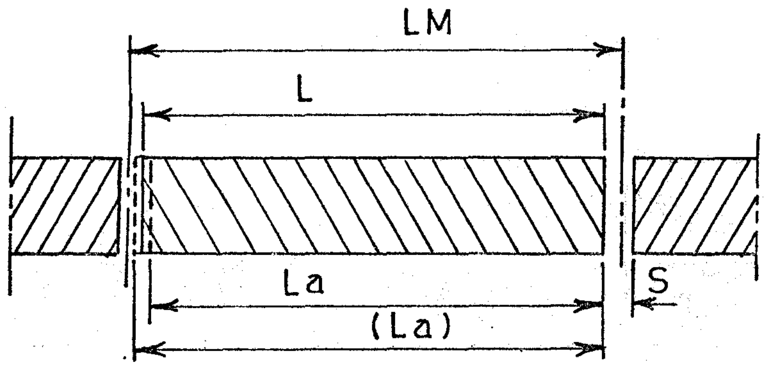
The house designer gains an immediate advantage in that standard details can be established and so there is then no need for fresh details for each phase of the project. The process of development requires immediate revision of drawings, and when those are of standard details the problem becomes much less time-consuming. Less time is therefore needed for drawings and more time is available to analyze user requirements and to tackle any particularly difficult problem.

2.7 MODULAR COORDINATES:

A much greater measure of standardization has been suggested in an intermediate step between a fully prefabricated system, in which every thing is predetermined, and fabrication on the site by traditional methods. So there was a need of standard for modular sizes.

The initial step in this direction was in 1936, by Albert Farwell Bemis, who proposed the Cubical Modular Method to improve the inefficient methods of assembly of unrelated materials and reduce the cost of building construction by applying industrial production techniques. He considered that four inches provided the largest dimensional increment for minimizing problems resulting from stocking and distributing standardized components, while preserving design flexibility to meet practical and aesthetic requirements. The 4-inch module was generally adopted as a standard in the late forties and early fifties because it differs only by 1.6% from ten centimeters which constitutes the obvious metric module.

In attempting to assemble a building from modular components made by different manufacturers, there must be a clear understanding of the tolerances of the production process, the distortion during transport and erection, and the relative movement of different parts due to temperature and moisture. The components themselves must be smaller than an exact multiple of the module by a clearly defined amount to allow them to fit into a modular space (see Figure 1).



LM Erection dimension= exact multiple of the module

L The theoretical dimension of the part

La The actual dimension

S Width of the joint

DIMENSIONS OF MODULAR PARTS

Figure: 1

2.8 SYSTEMS OF PROPORTION AND PREFERRED DIMENSIONS:

No standardization can be achieved if every multiple of 4 inches is an admissible modular size, and one effect of modular coordination has been a renewed interest in the classical systems of proportioning and preferred sizes.

The relation between human scale and the proportions of buildings was considered by Vitruvius, in Book III, Chapter 1, On Symmetry; In Temples and in the Human Body, "Since nature has designed the human body so that its members are duly proportioned to the frame as a whole, it appears that the Ancients had good reason for their rule, that in perfect buildings the different members must be in exact symmetrical relations to the whole general scheme." (14).

The concept that certain ratios produce harmony both in music and in architecture is mentioned by Alberti: "The Rule of these Proportions is best gathered from those things in which we find Nature herself to be most complete and admirable, and indeed I am everyday more convinced of the Truth of Pythagoras' Saying that Nature is sure to act consistently, and with a constant Analogy in all her Operations; from which I conclude that, the same Numbers, by means of which the Agreement of Sounds affects our Ears with Delight, are the very same which please our Eyes and our Mind." (12).

Many ratios such as $5/3 = 1.666$, or the Golden Rule of 1.618, or $\theta = 1 + \sqrt{2}$, or $\phi = (1 + \sqrt{5})/2$, were suggested to be basis of modular size increments. The use of Fibonacci series made the admissible modular dimensions become more widely spaced with increasing size. This overcomes the difficulty of Bemis' original proposal to make every multiple of four inches an admissible modular size, whereby the nearest modular size above eight inches is 12 inches (an increase of 50%), but the nearest modular size above 240 inch is 244 inch (an increase of less than 2%) (9).

2.9 CONCLUSION:

It seems likely that a successful solution will have to abandon the classical theory, and approach the problem experimentally. Certain dimensions can be fixed permanently because they depend on the human figure, these include floor-to-ceiling heights for all normal stories and the dimensions of all but ceremonial staircases. For others, such as window sizes, we must admit a small number of preferred sizes in 4 inch increments. For small dimensions such as wall thickness we have to accept increments of 1 inch, but still with a strictly defined range of preferred sizes.

CHAPTER III

A NEW PROPOSED HOUSE BUILDING SYSTEM

A new prefabrication system is proposed*, which, it is believed, satisfies many of the requirements of an ideal housing system. It combines many of the features of existing systems.

The houses would be built of predesigned and prebuilt material units. These units are of modern size and design, taking full advantage of all materials. It is similar to the precut system, except that material units are larger and highly standardized, so that relatively few units can be applied to a great many house designs. This is done by incorporating the very important modular concept.

The structural system uses rigid posts, mounted in concrete piers. The walls are non-structural, except to provide some resistance to racking. Standardized roof beam sections are used. The low pitch roof is covered with built-up tar and gravel roofing or special metal roofing panels. The houses would normally have no basement, although basements could be provided as a custom feature.

A hot air perimeter heating system would be used with ducts running around the slab perimeter and diffusing warm air up through registers below windows. The furnace would be a counterflow oil or gas fired type. An alternate and more expensive system is electric heating.

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* This system depends mainly on an unpublished report by Siddall, J.N. on, "A New System of Housebuilding", March 1971.

The components are described in detail below and will illustrate the advantages of modular design.

3.1 MODULAR PLANNING:

Modular planning is the use of a standard module as measuring unit when designing a house. All, or almost all, horizontal room dimensions must be whole multiples of the module. This permits the use of standard size components.

Architects have found that 40 inches is in many respects the ideal module size; and it has been used in this scheme.

Other modules are used to some degree in all construction. Forty-eight inches is an obvious module, since many materials are sold in four foot widths.

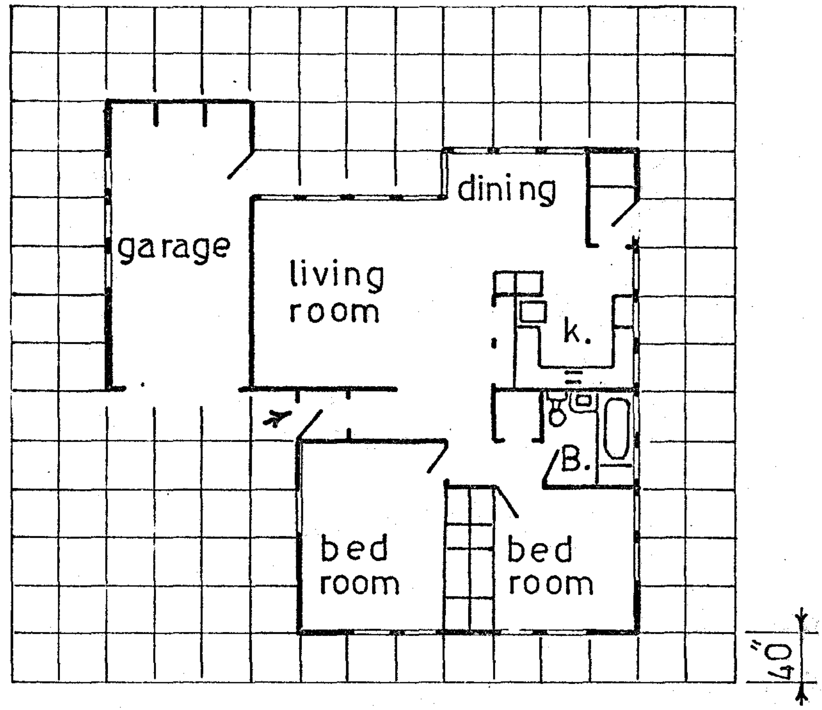
Although modular design limits to some extent the flexibility of house planning, the limitation is not serious and almost any conventional plan can be closely approximated in modular planning.

Examples of modular planning are given in Figure 2.

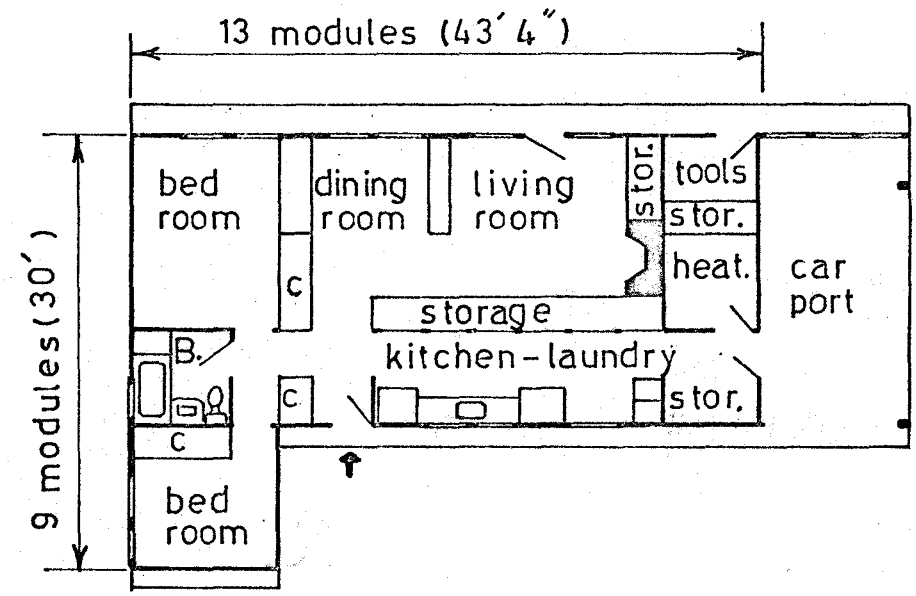
3.2 LIMITATIONS ON FLEXIBILITY:

Structural and economic considerations impose certain restrictions on complete modular flexibility, just as in conventional construction. These limitations are shown in Figure 3, which shows available house widths and types of roof.

For the most economic use of material, it is considered desirable not to exceed an unsupported roof span of five modules (16'8") and interior posts must be provided where necessary to satisfy this. The seriousness of this limitation is minimized by the archway girder described later on.



A PLAN SUPERIMPOSED ON MODULAR GRID

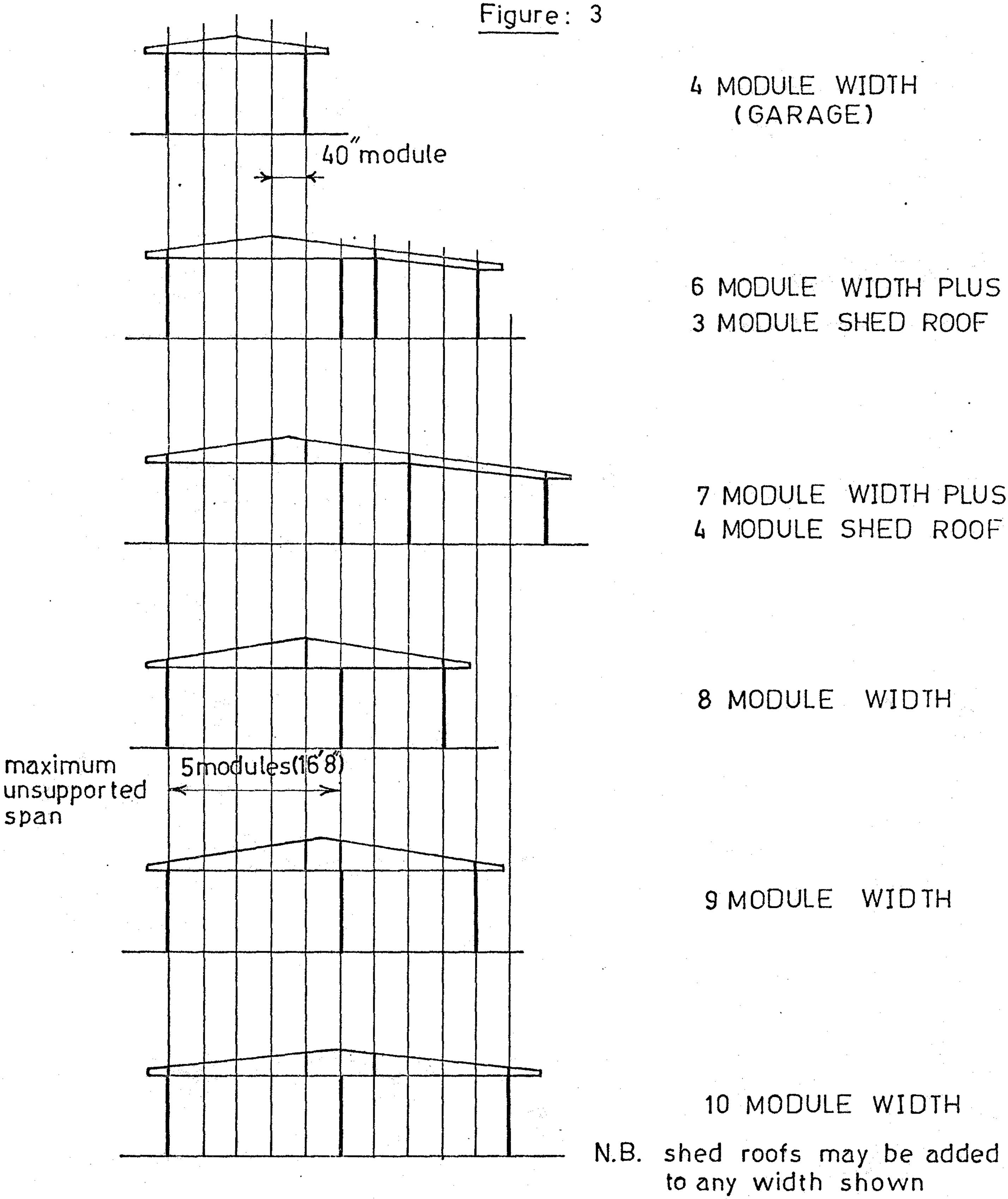


A PLAN BASED ON C.M.H.C. DESIGN 127

MODULAR PLANNING

Figure: 2

Figure: 3



END ELEVATION SHOWING AVAILABLE HOUSE WIDTHS

3.3 ROOF BEAMS:

The beams are wooden beams with plywood webs. Beams are spaced 40" apart.

It is possible to confine roof beam sections to the following standard units:

Two module centre section;
2 - one module centre sections,
three module beam section,
four module beam section,
two or three cornice sections,
two, three or four module shed beams.

Sections are bolted together through steel plate connectors. Where a post occurs at a joint, a lug is provided on the connector through which the beams are spiked or screwed to the post.

The roof pitch is 4 inches per module or 1 in 10. This pitch is based on economic roof beam design.

The roof beams are believed to provide a small saving in material over conventional construction.

The beams are illustrated on the following drawings, where Figure 4 shows the standard beam sections, and Figure 5 shows the connection of these beams.

3.4 POSTS AND FOUNDATIONS:

Posts are of 4" x 4" (full dimension) wood. They are spaced 40" apart along all outside walls and interior partitions. Isolated posts may be used. Posts will be 11 feet long, including three feet extending into

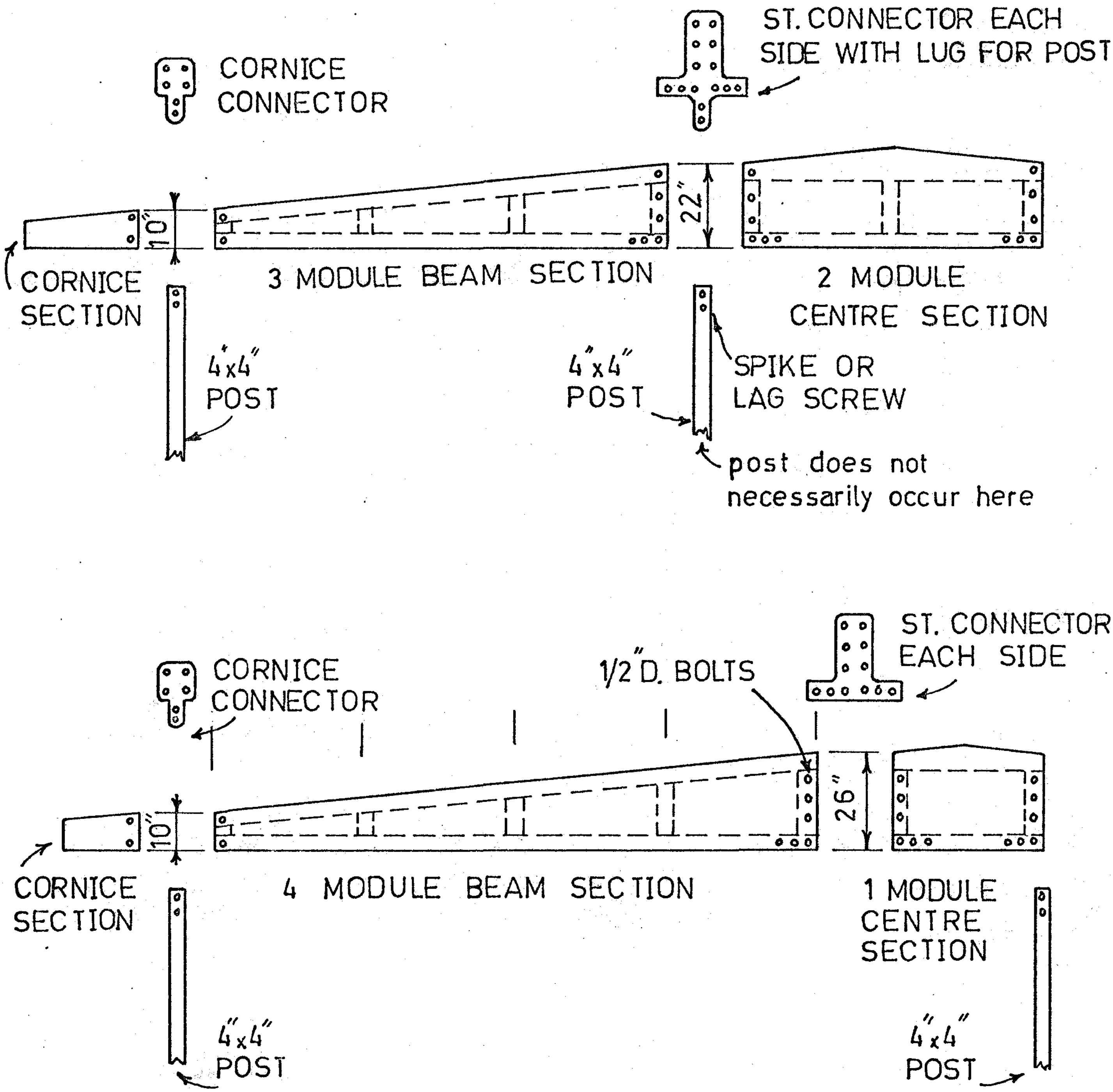
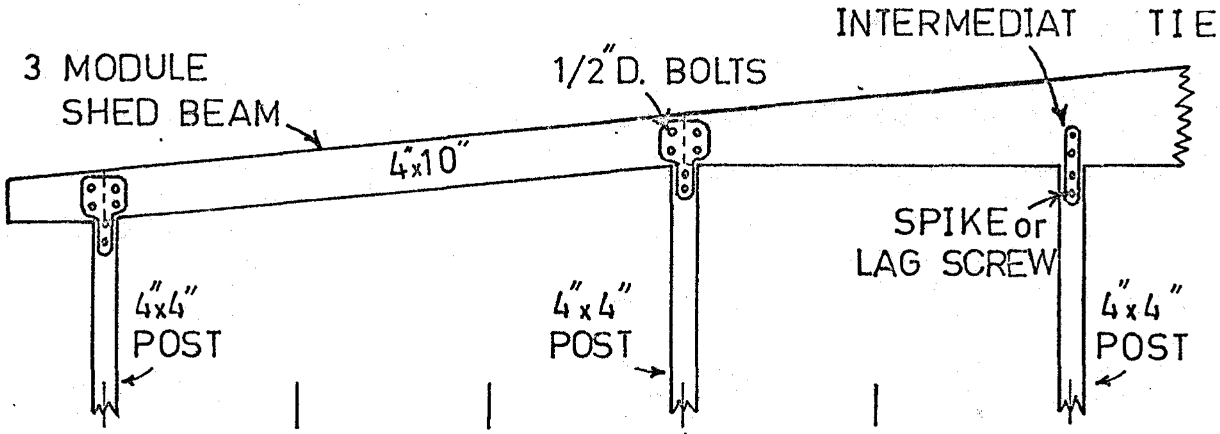


Figure: 4

ELEVATIONS SHOWING STANDARD BEAM SECTIONS

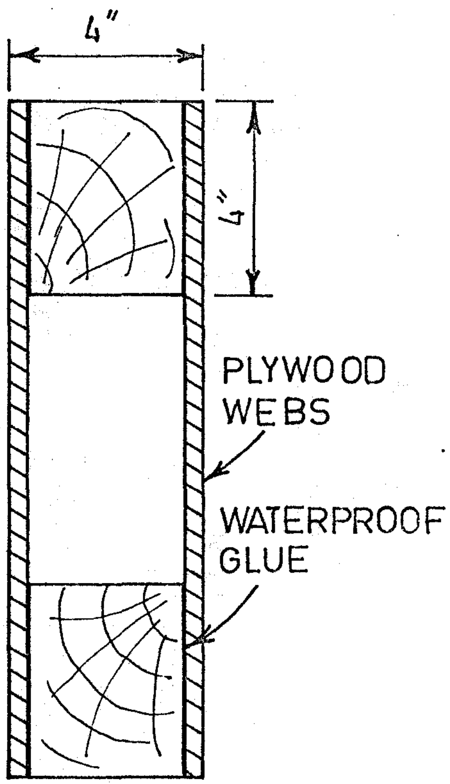
SCALE 1:32

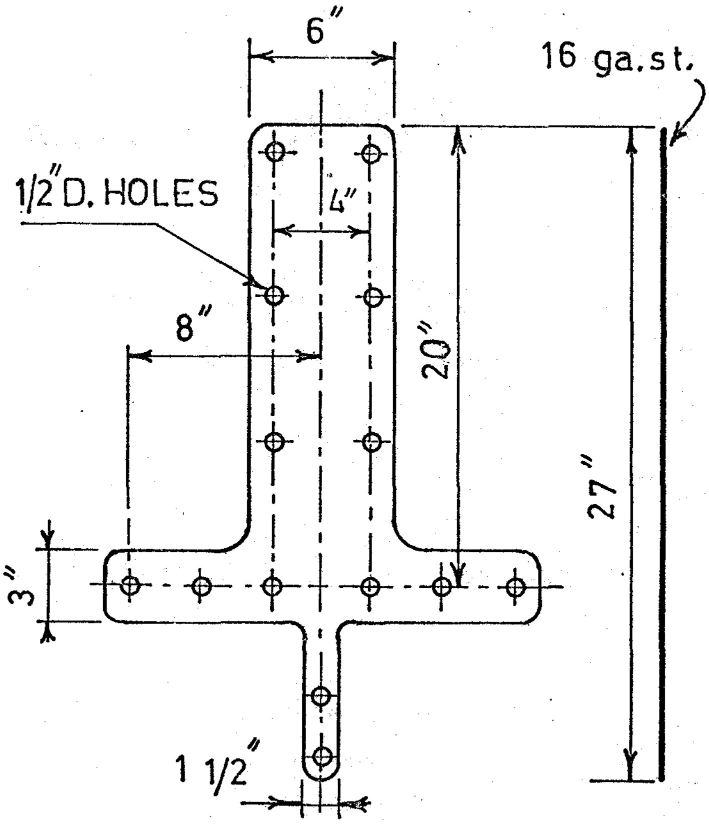


note: similar 2&4 module shed beams having the same section are not shown.

ELEVATION SHOWING STANDARD SHED BEAMS

SCALE 1:32





CROSS SEC. OF ROOF BEAM

SCALE 1:4

BEAM CONNECTOR

SCALE 1:8

Figure : 5

the piers. It is believed the posts represent an appreciable saving in material over conventional construction. There are no plates, no headers or lintels at doors and windows and no diagonal bracing.

The posts are rigidly supported by concrete piers. Figure 6 and Figure 7 illustrate how the posts are grouted into the hollow piers. The piers consist of two precast sections, each section two feet high. The bottom section will have the lower half solid. Local 12" square concrete footings support the piers.

Prefabricated ground wall panels are mounted between piers to replace the conventional foundation wall. These panels are 1/4" thick asbestos board bonded to 1" thick rigid insulation. The insulation will be Fiberglass floor slab edge (1" x 12" x 36") or Styrofoam (1" x 12"). The panels will be 48" deep by 31-1/4" long. Floors will be conventional concrete slabs on ground.

The bearing capacity of piers "carefully manufactured" in a factory is better and more uniform than that poured in place and produced under less favourable conditions. Special attention has to be given to the joints between the prefabricated piers and the posts, so that these joints will actually be capable of transmitting the force to which they are subjected. Also, special attention has to be given to these load bearing elements (piers) while transporting to the building site to prevent damage under the entirely different stress conditions.

3.5 WALLS:

In recent years, the outside walls have continued to change rapidly, until now their appellation "Curtain Walls" is no misnomer, but an accurate

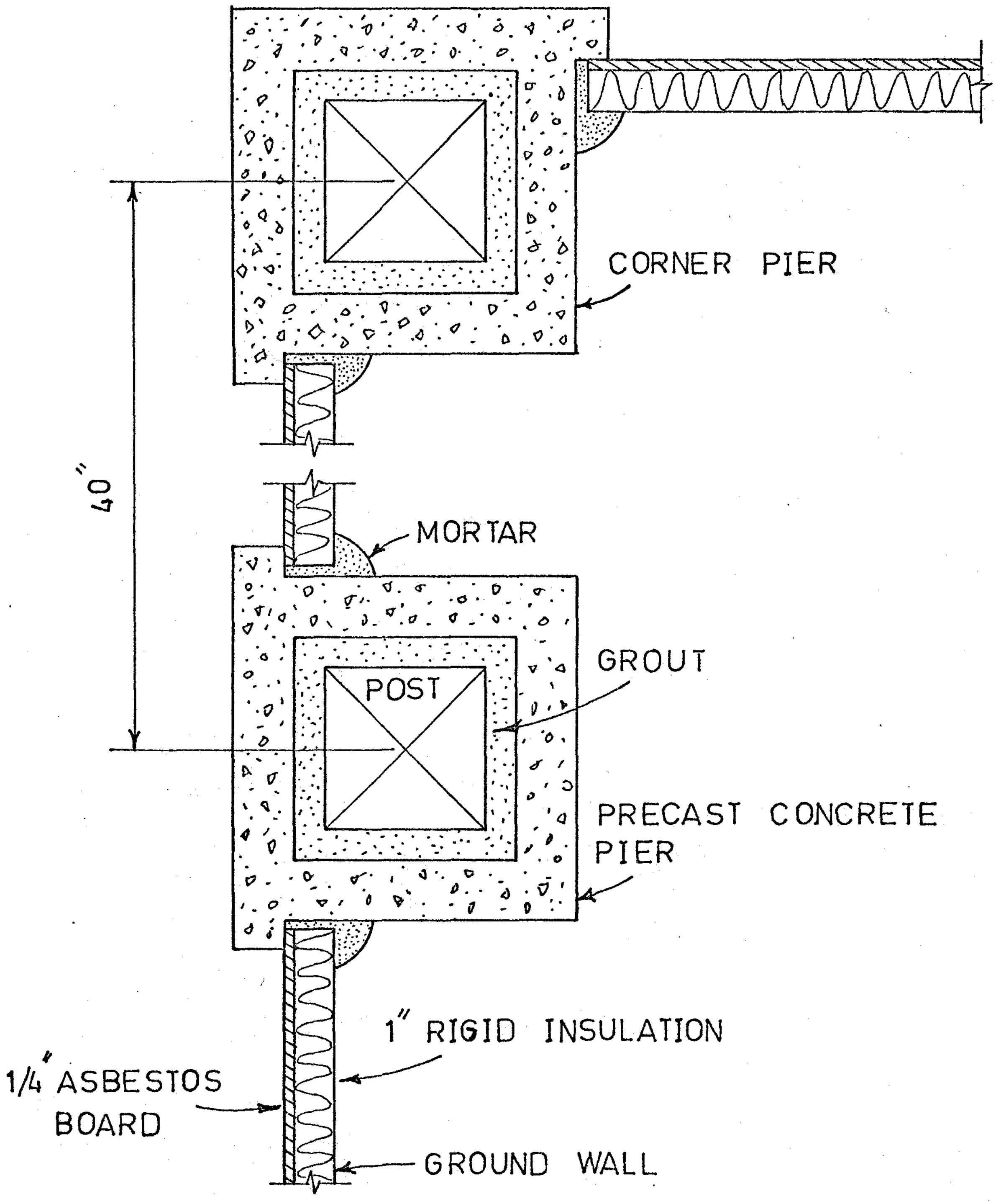


Figure: 6

HORIZONTAL SECTION SHOWING FOUNDATION & GROUNDWALL

SCALE 1:4

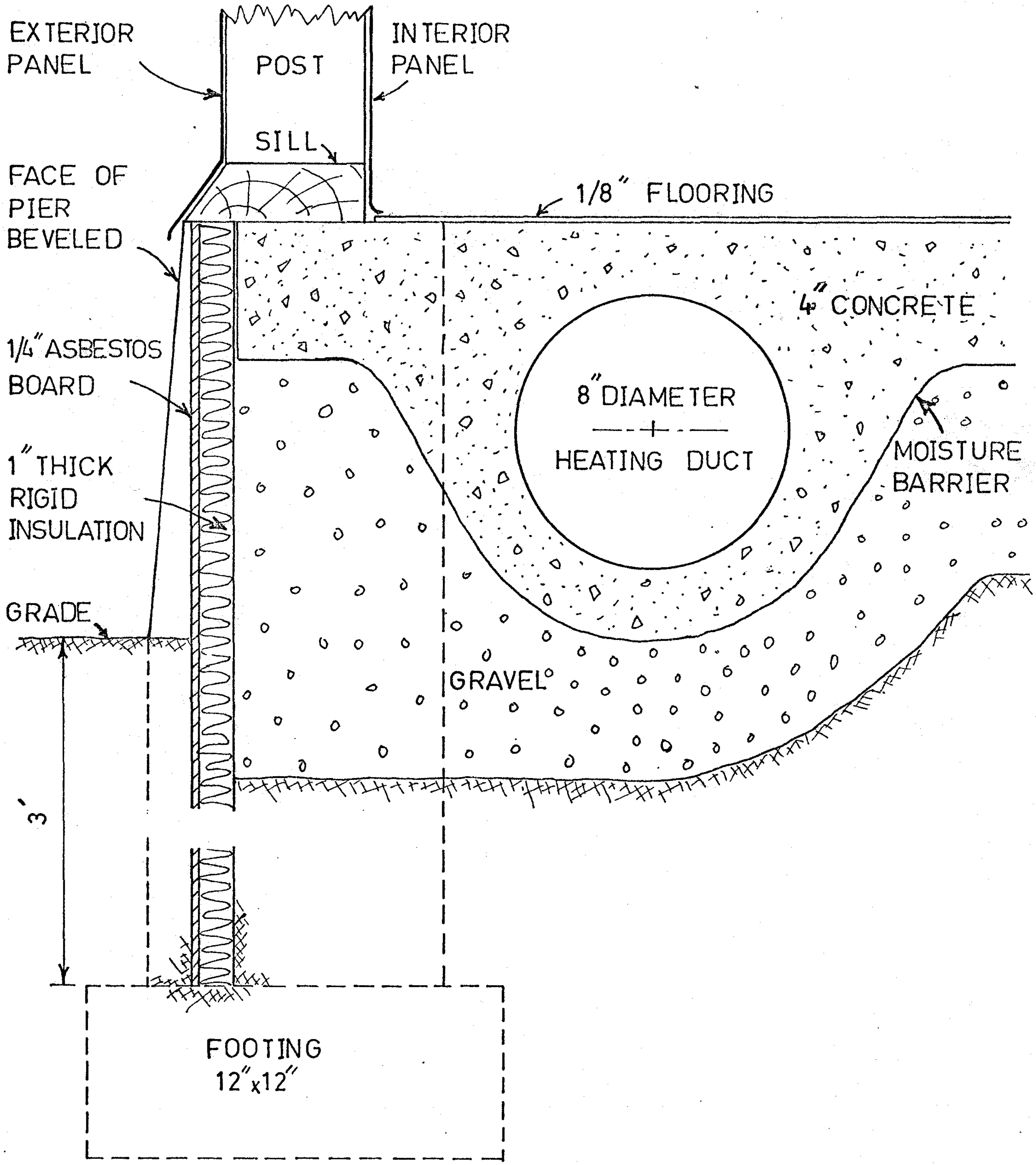


Figure: 7

VERTICAL SECTION THROUGH GROUNDWALL SHOWING FOUNDATION

SCALE 1:4

description of the light, thin, prefabricated panel cladding. The development of the modern curtain wall is to be welcomed as it is logical and reduces unnecessary weight, it is also capable of sound technical design if the conditions (inside and outside) to which it is to be subjected are fully recognized.

In general, the scheme is to have separate inside and outside panels. Assembly will be on the site.

A variety of materials are possible, perhaps the most elegant being steel or aluminum stampings or formed plastic or composition sheets. It may be difficult to beat conventional material costs, particularly plaster interiors, with which lath board panels could be used.

These walls are curtain walls, carrying no vertical loading. Exterior panels will, however, resist racking loads. Thus they are fastened rigidly on the sides to posts, but will float against the roof. The metal panels shown in Figure 8 are positioned and interior panels partly held by the small steel clips shown on the sketch. Two or three of these clips would be used per panel edge.

Wall panels will be prefinished. Outside panels will have two inches of glass wool insulation (or similar) bonded to the inner surface at the factory.

This scheme of separate exterior and interior panels has advantages over completely preassembled panels:

1. Reduced inventory.
2. Easier shipping, handling, and mounting.
3. Accessibility to inside of wall after erection.
4. A panel can be easily replaced.

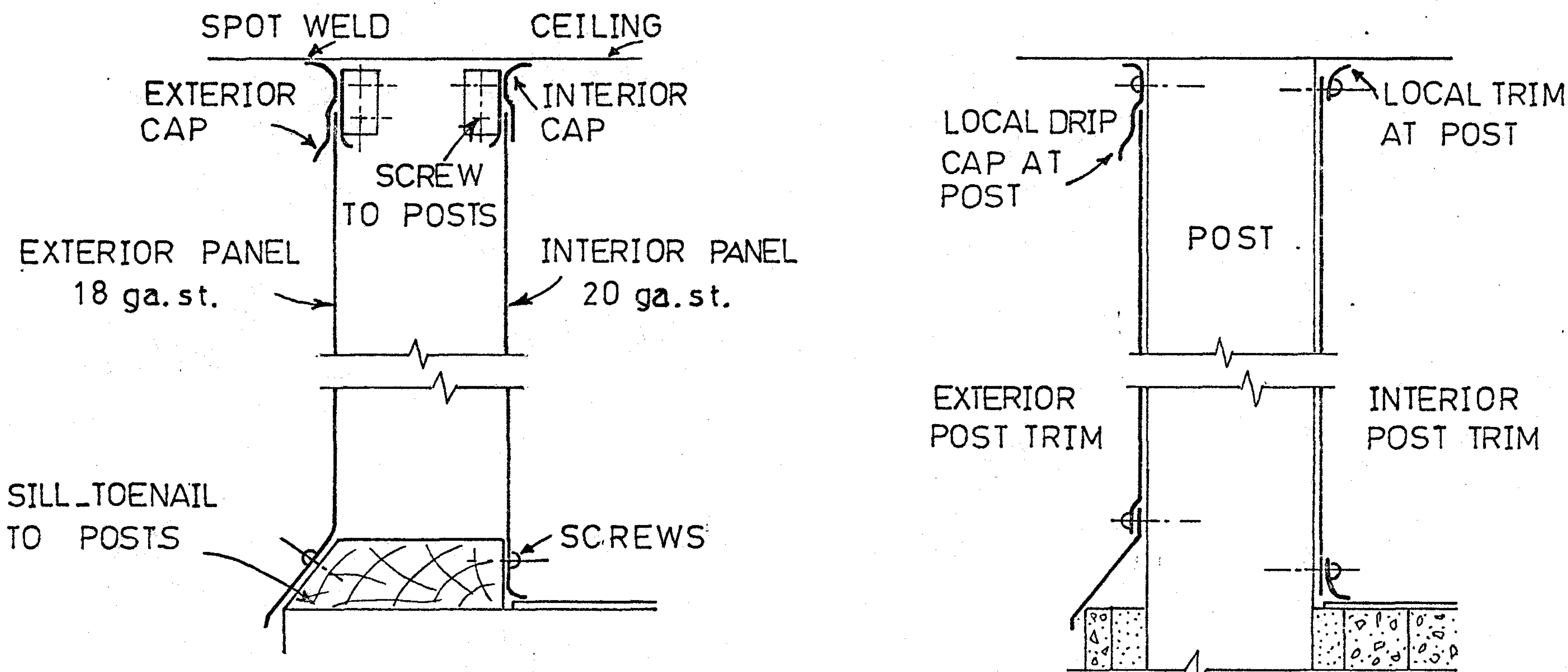


Figure: 8a

VERT. SEC. THRU' EXT. WALL SHOWING METAL PANEL
SCALE 1:4

VERT. SEC. THRU' POST
SCALE 1:4

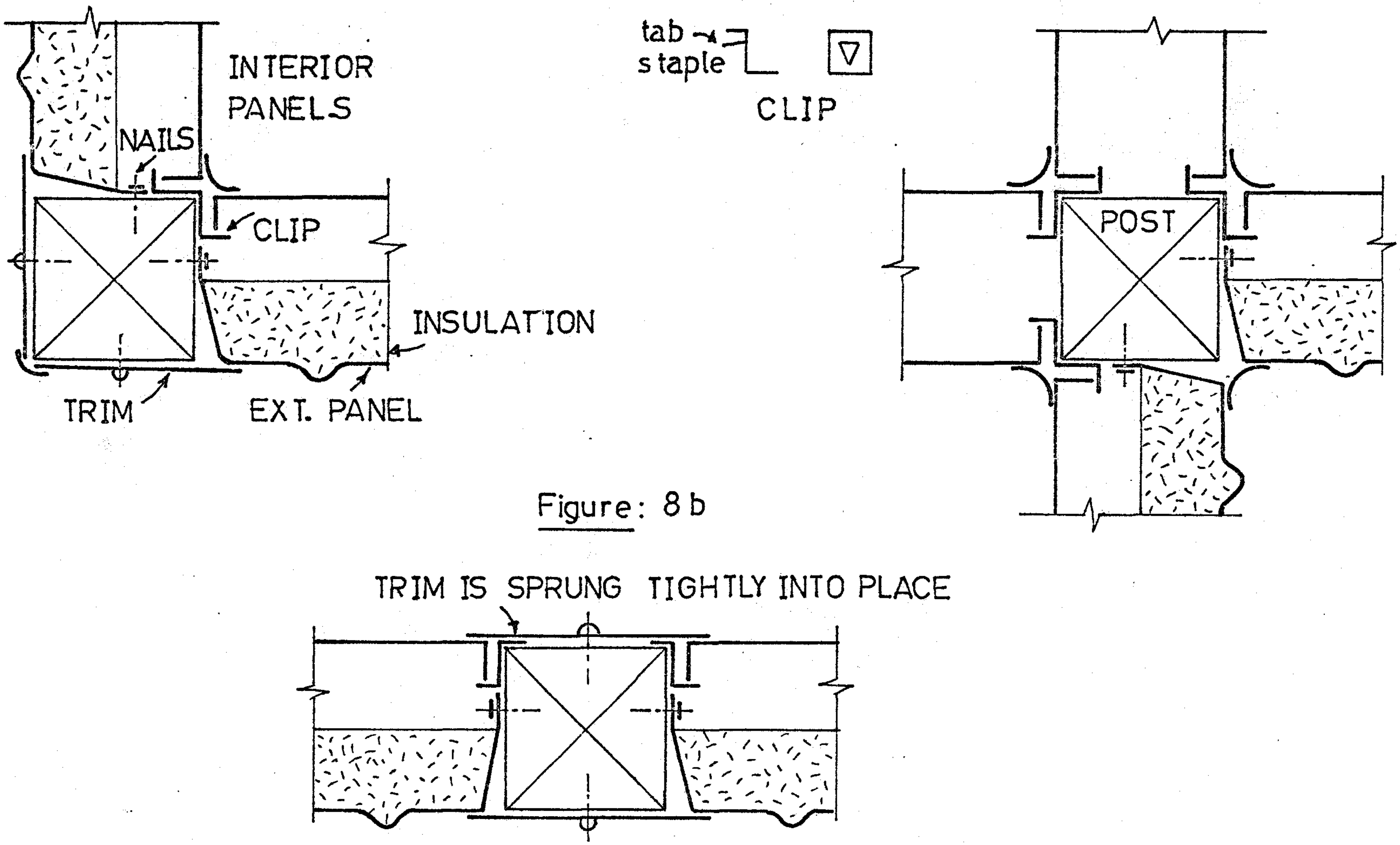


Figure: 8 b

TYPICAL HORIZONTAL WALL SECTIONS SHOWING METAL PANELS

SCALE 1:4

Exterior panels of 18 gauge steel or equivalent aluminum are stiffened by beading vertically and horizontally. Interior steel panels of 20 gauge will be stiffened by spot welded angles. Interior lath board panels would also require stiffeners (see Figure 9).

Standard wall headers are shown in Figure 10 which would mount horizontally at any point between posts; and would support plumbing fixtures, cabinets or other fixtures or shelves.

Comparative estimated retail costs of various panels and materials are shown below:

Material	Location	Panel Cost Per Sq.Ft.	Material Cost Per Sq. Ft.
Steel (unpainted)(18 ga.)	Exterior	25¢	
Aluminum (14 ga.)	Exterior	54¢	
Plywood (3/8")	Exterior	22¢	
Conventional composition sheathing & cedar siding	Exterior		22¢
Steel (20 ga.)	Interior	20¢	
Plastic	Interior	40¢	
Composition lath & plaster (including plastering labour)	Interior		15¢
Plywood (1/4")	Interior	16¢	

Plastics can be used for mass production of light-weight, thin surface finishes that are durable and washable. They keep their colours and need little maintenance, but they are more expensive than traditional plastered and painted walls.

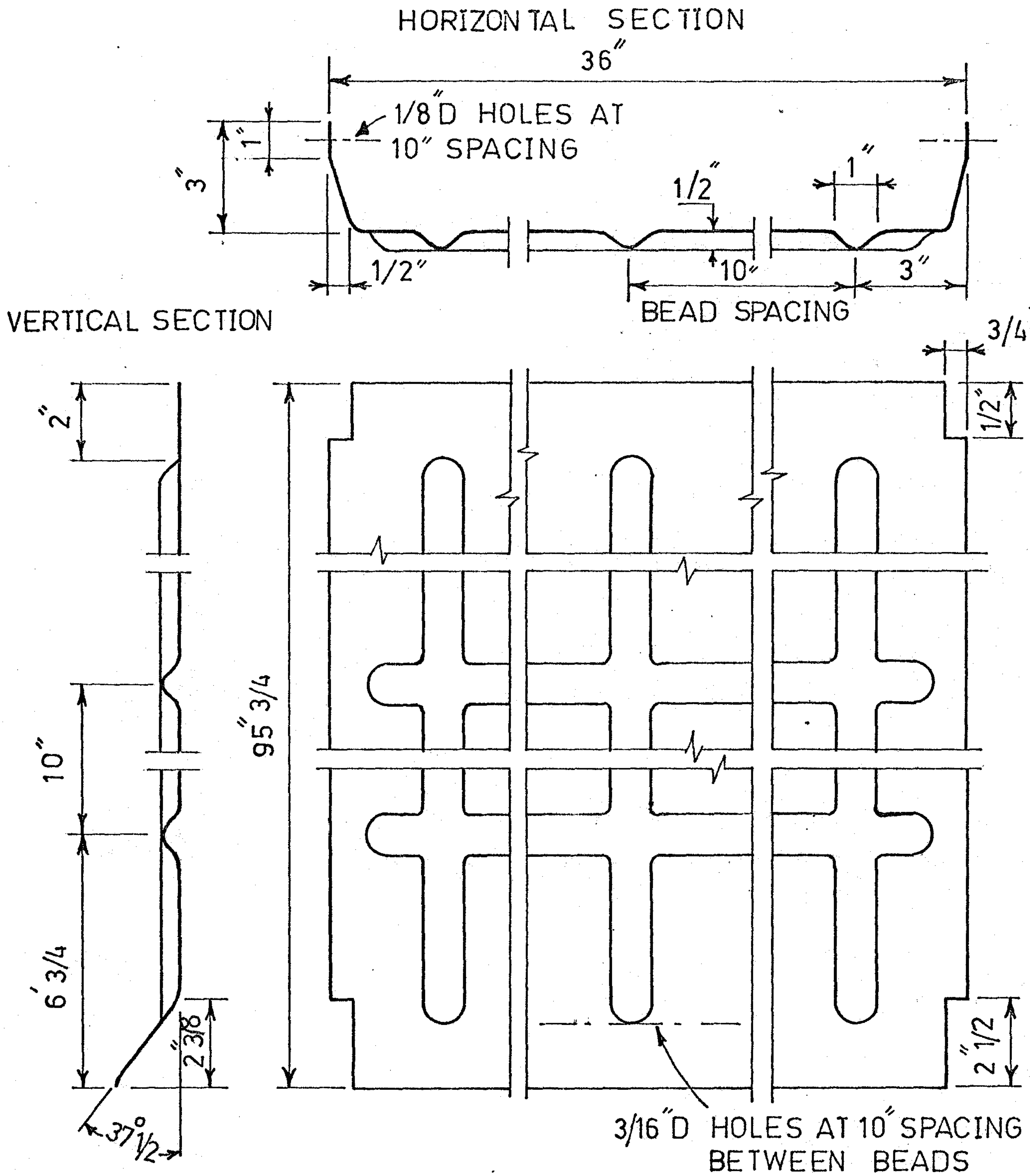


Figure: 9

EXTERIOR WALL PANEL OF STEEL

SCALE 1:4

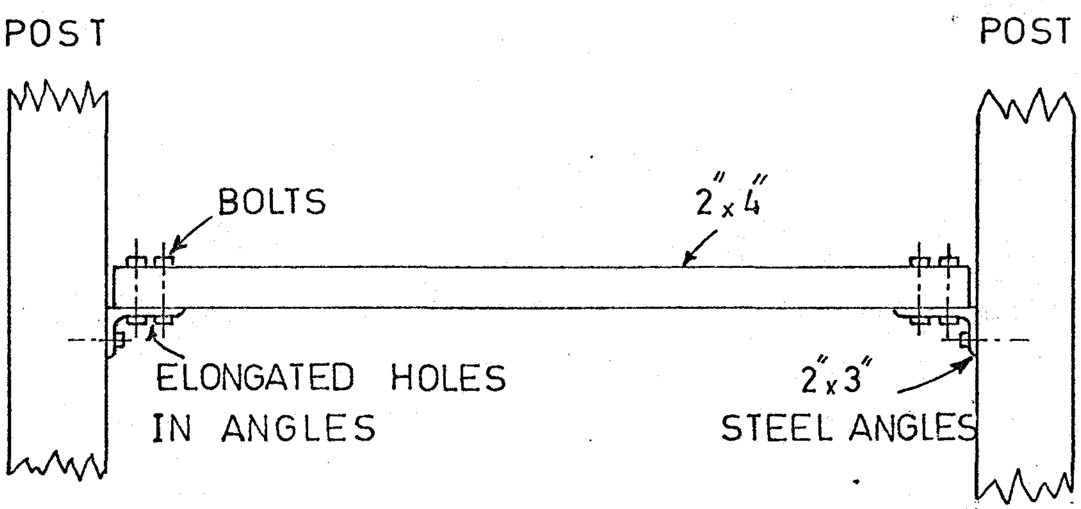
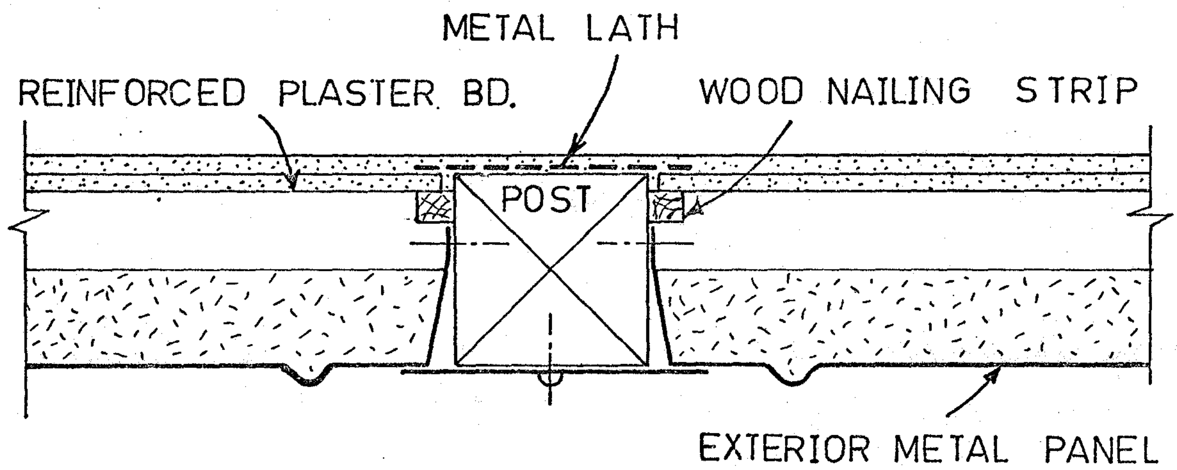


Figure : 10

ELEVATION SHOWING WALL HEADER

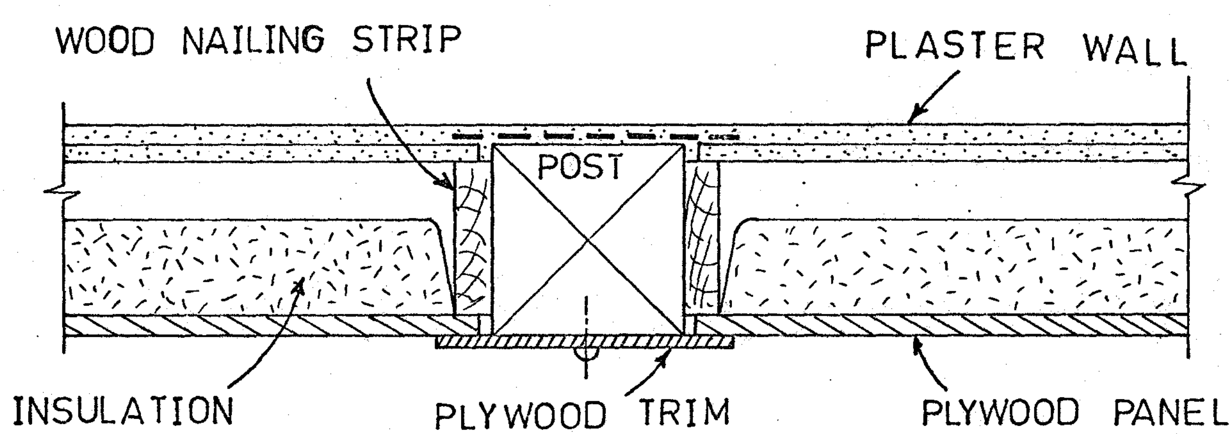
SCALE 1:4



HORIZONTAL SEC. SHOWING PLASTER INTERIOR WALL AND METAL EXTERIOR PANEL

SCALE 1:4

Figure : 11



HORIZONTAL SEC. SHOWING PLASTER INTERIOR WALL AND PLYWOOD EXTERNAL PANEL

SCALE 1:4

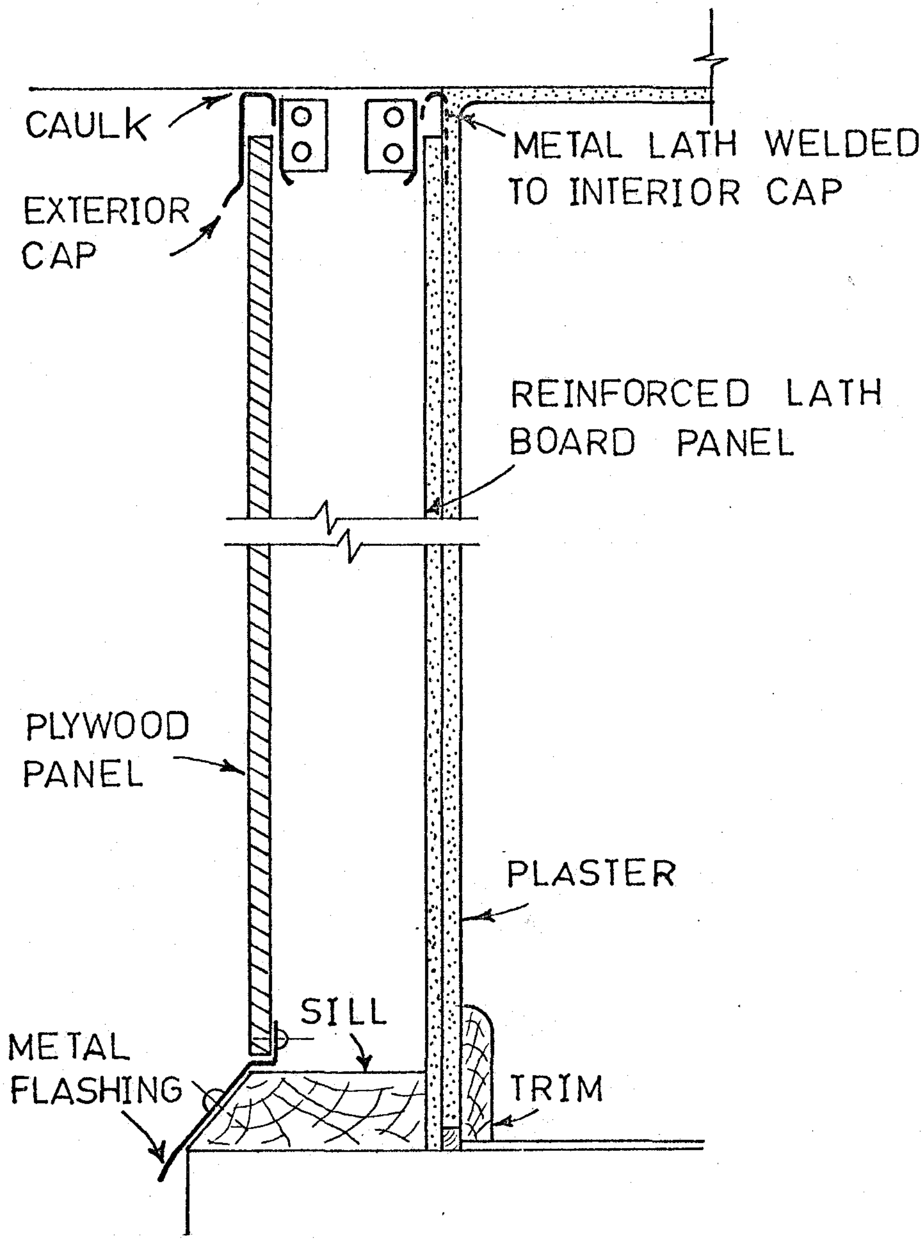


Figure: 12

VERTICAL SEC. THRU' EXTERIOR WALL
SHOWING PLYWOOD EXT. PANEL & PLASTER INTERIOR

SCALE 1:4

3.6 WINDOWS AND DOORS:

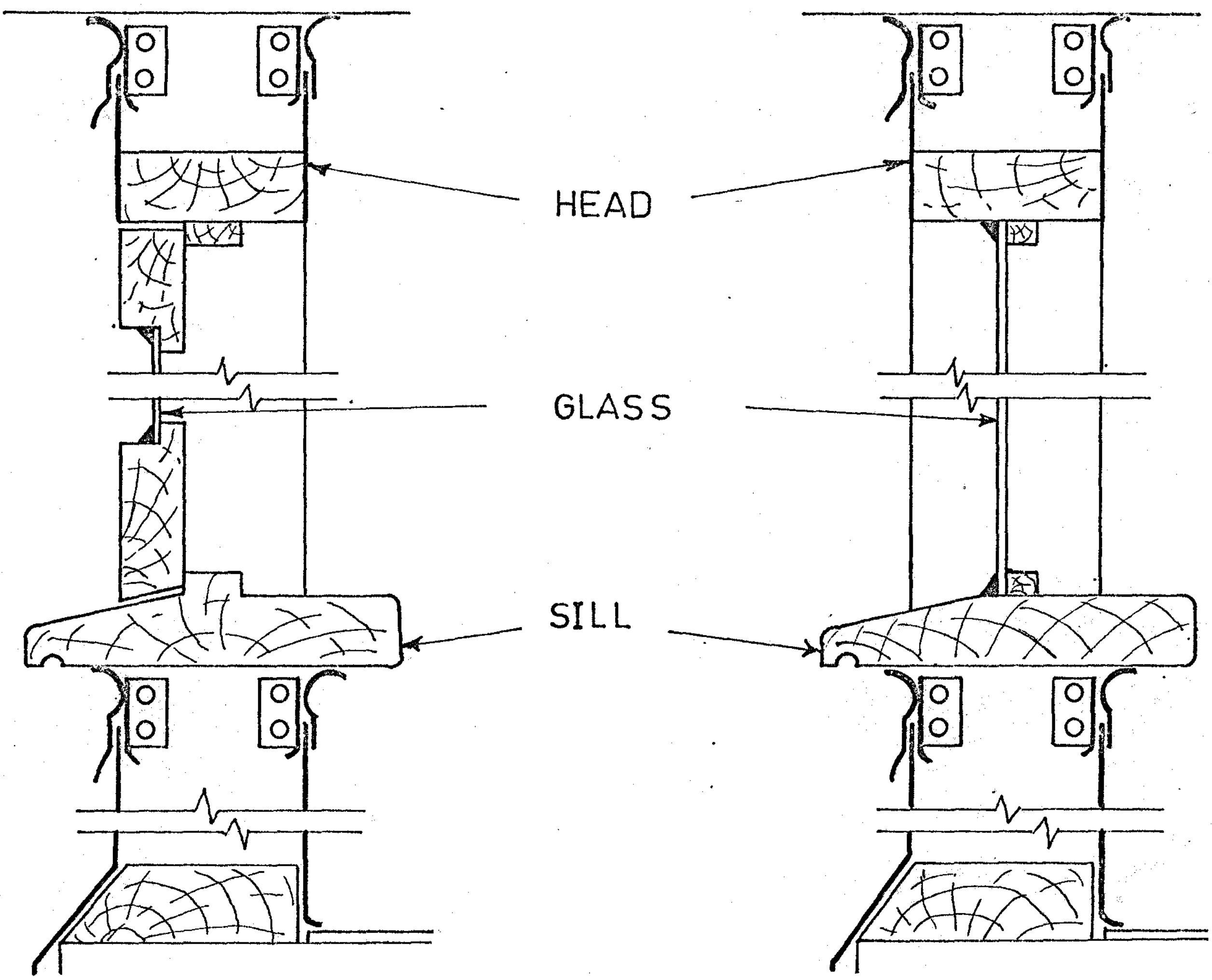
Windows and doors will be shipped as prehung assemblies in the frames. They will be nailed through the side frames to the posts. It will be noted on the drawings that special short wall panels are mounted under the window units. Door units, which are not shown, are mounted very similarly to window units, except for the sill.

It is believed that casement type windows are best adapted to this type of construction, although double hung windows are quite feasible (see Figure 13).

3.7 ROOF:

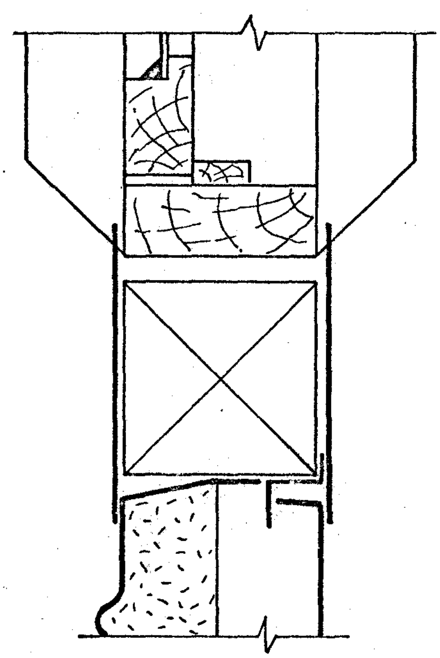
A conventional built-up tar and gravel roofing may be used. This is supported by 5/16" thick plywood sheathing, in turn supported by roof beams at 40" spacing and 2" x 4" headers at 20" spacing. The plywood sheets would be shipped in standard sizes, 40" wide by 40" or 80" long; thus again utilizing the module standard. Steel hangers are used to support the ends of the headers. Material used would be comparable to conventional construction.

An alternative roof system might be formed of metal or asbestos roofing panels, requiring no additional sheathing. A possible basis for development of such as aluminum roofing panel is suggested in Figure 14 and Figure 15. This roofing system better satisfies prefabrication principles than built-up roofing.



VERTICAL SEC. THRU' CASEMENT WINDOW

VERTICAL SEC. THRU' FIXED WINDOW



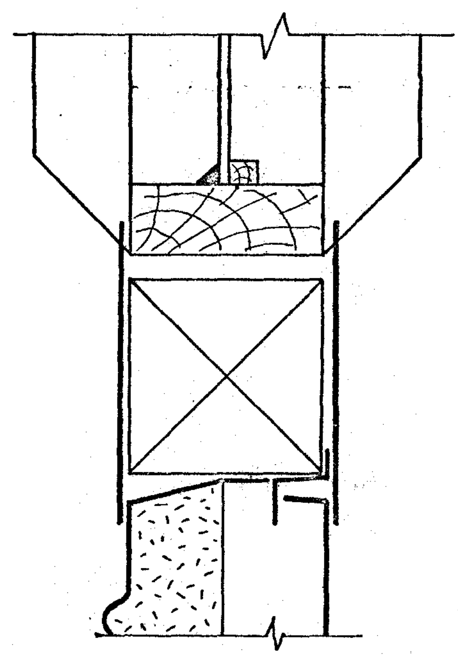


Figure:13

CASEMENT WINDOW JAMB

FIXED WINDOW JAMB

SCALE 1:4

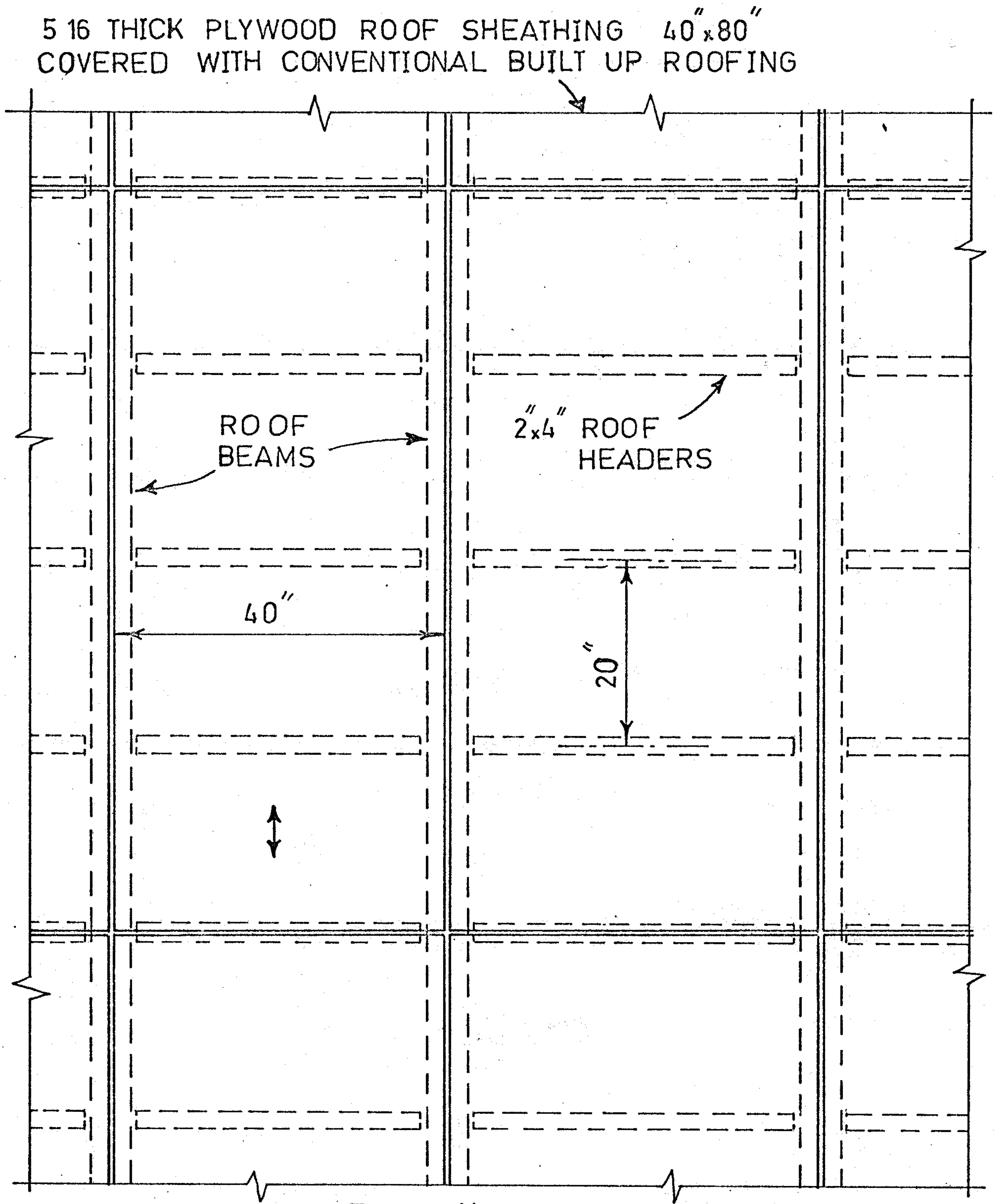
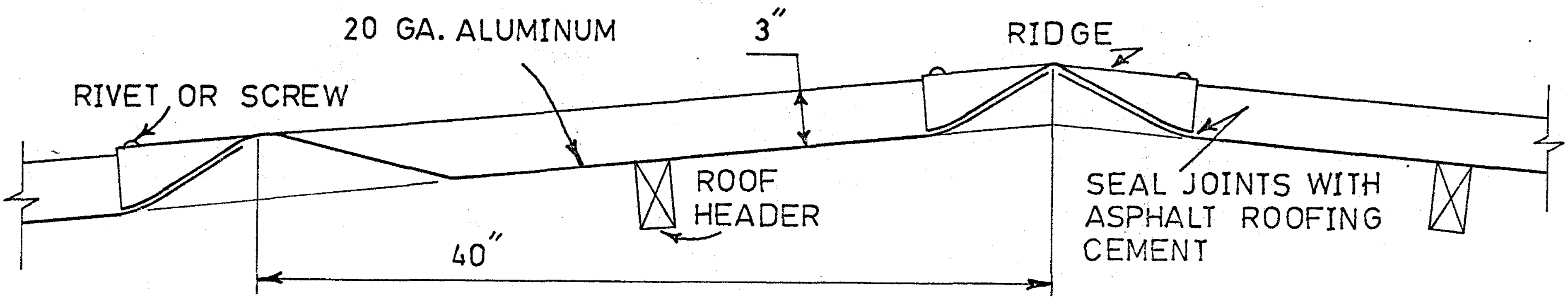


Figure: 14

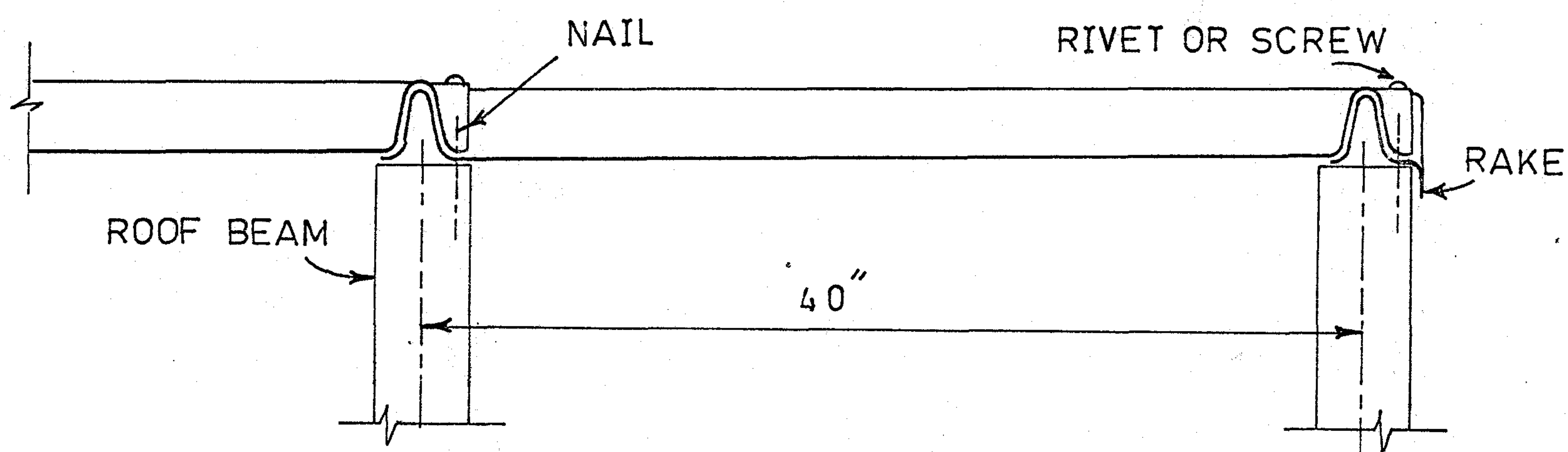
PLAN SHOWING ROOF SHEATHING & SUPPORTING STRUCTURE

SCALE 1:16



CROSS-SECTION OF METAL ROOFING PANEL

Figure: 15



LONGITUDINAL SECTION OF METAL ROOFING PANEL

SCALE 1:8

3.8 CEILING:

Plywood celings - two standard plywood ceiling panels would be provided, 40" x 40" and 40" x 80". These panels have insulation and stiffeners factory attached. Where necessary, corners at posts will be cut at the site. Panels are supported along roof beams by extruded aluminum battens, screwed to the beams (see Figure 16).

Plasterboard or lath and plaster ceiling - plasterboard or lath panels would be made up similarly to the plywood panel described above. The lath could then be plastered in the conventional way.

3.9 EAVES:

Soffits, or underside of eaves are similar to ceiling panels, using 1/4" plywood with an inner edge stiffener, but no insulation. Soffits contain in each module one screened 4" x 12" vent.

Eaves would be available in several widths. A full module width would be supported by isolated posts (see Figure 17).

3.10 RAKE:

The rake, or end eave, is treated similarly to the eave, and would be available in several widths. A rake without overhand could also be used. This is illustrated in Figure 18.

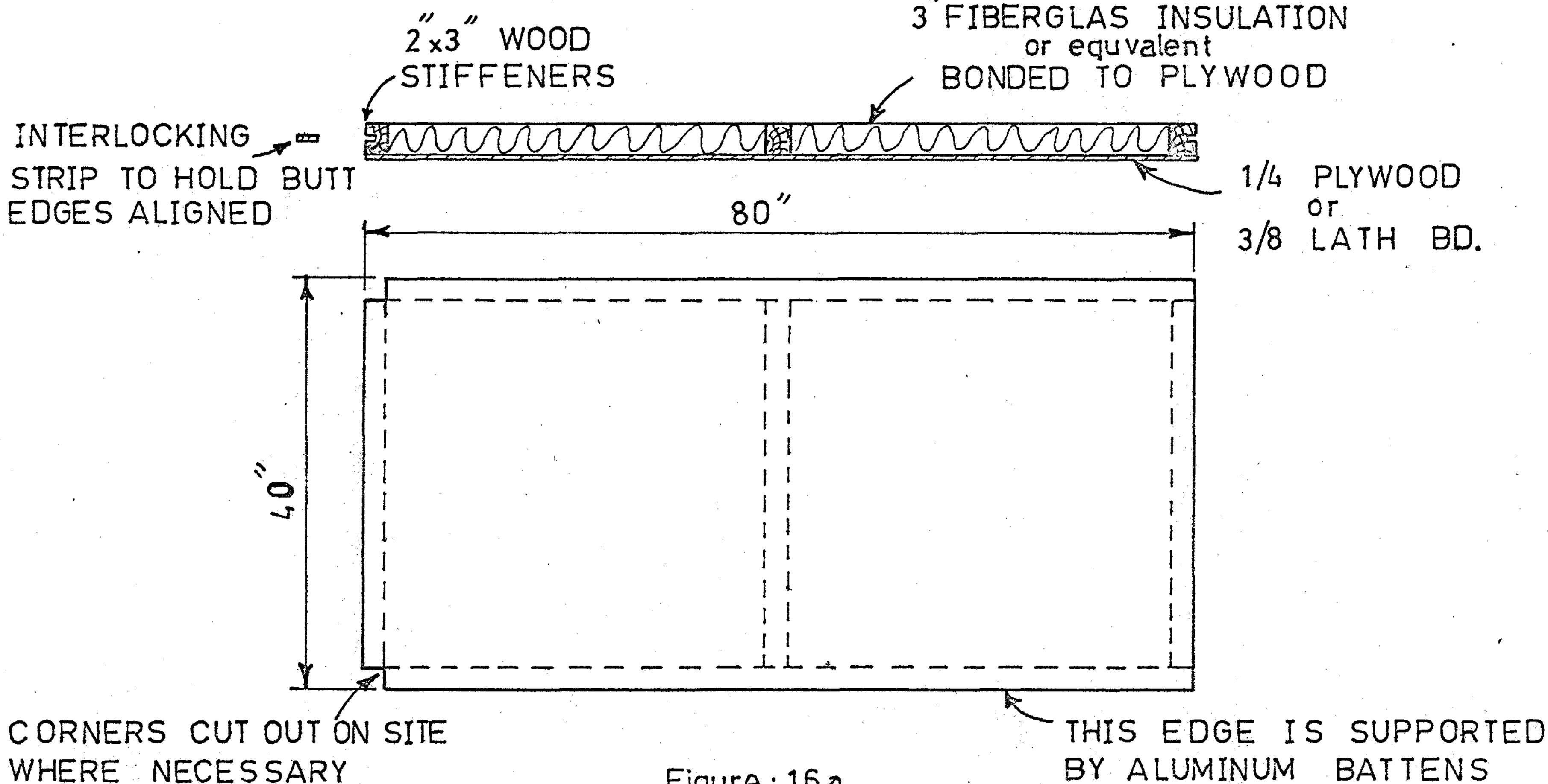
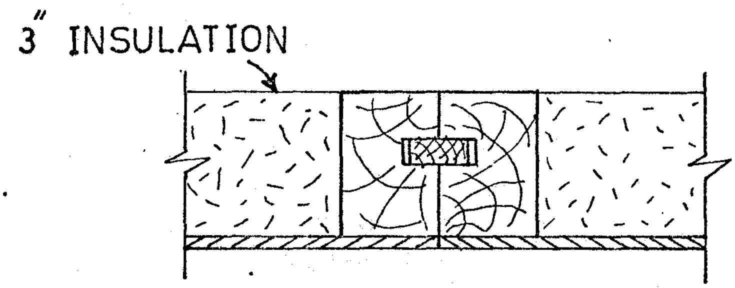


Figure: 16 a

CEILING PANEL

SCALE 1:16



SECTION SHOWING INTERLOCKING OF PANEL ENDS

SCALE 1 : 4

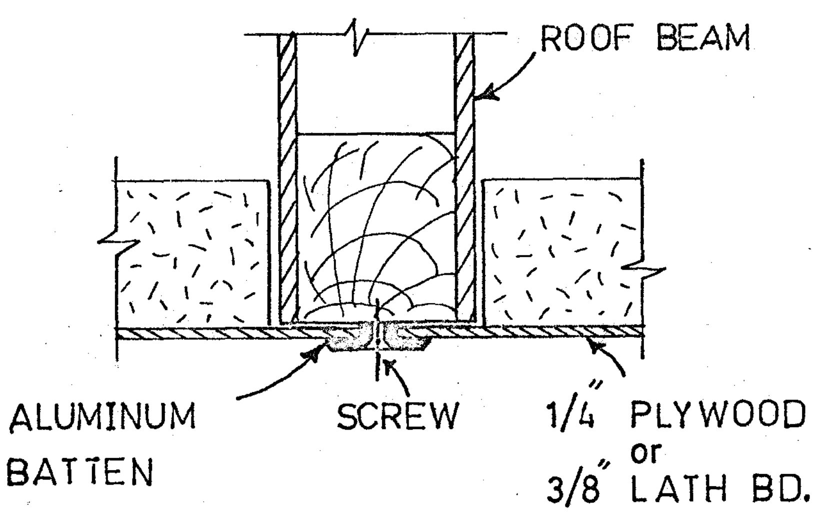


Figure: 16 b

SECTION SHOWING EDGE SUPPORT OF CEILING PANEL

SCALE 1 : 4

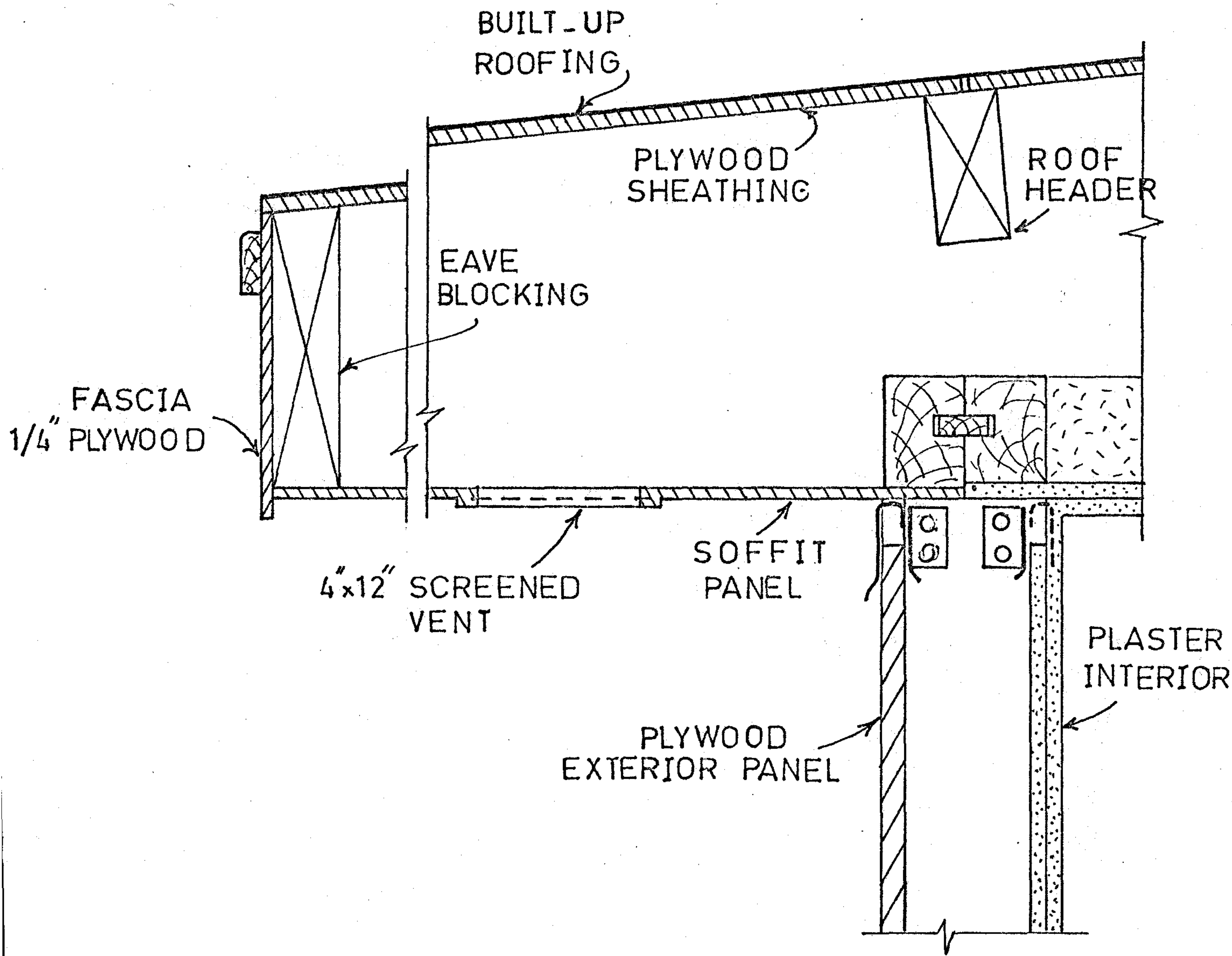


Figure: 17

SECTION SHOWING EAVE DETAILS

SCALE 1:4

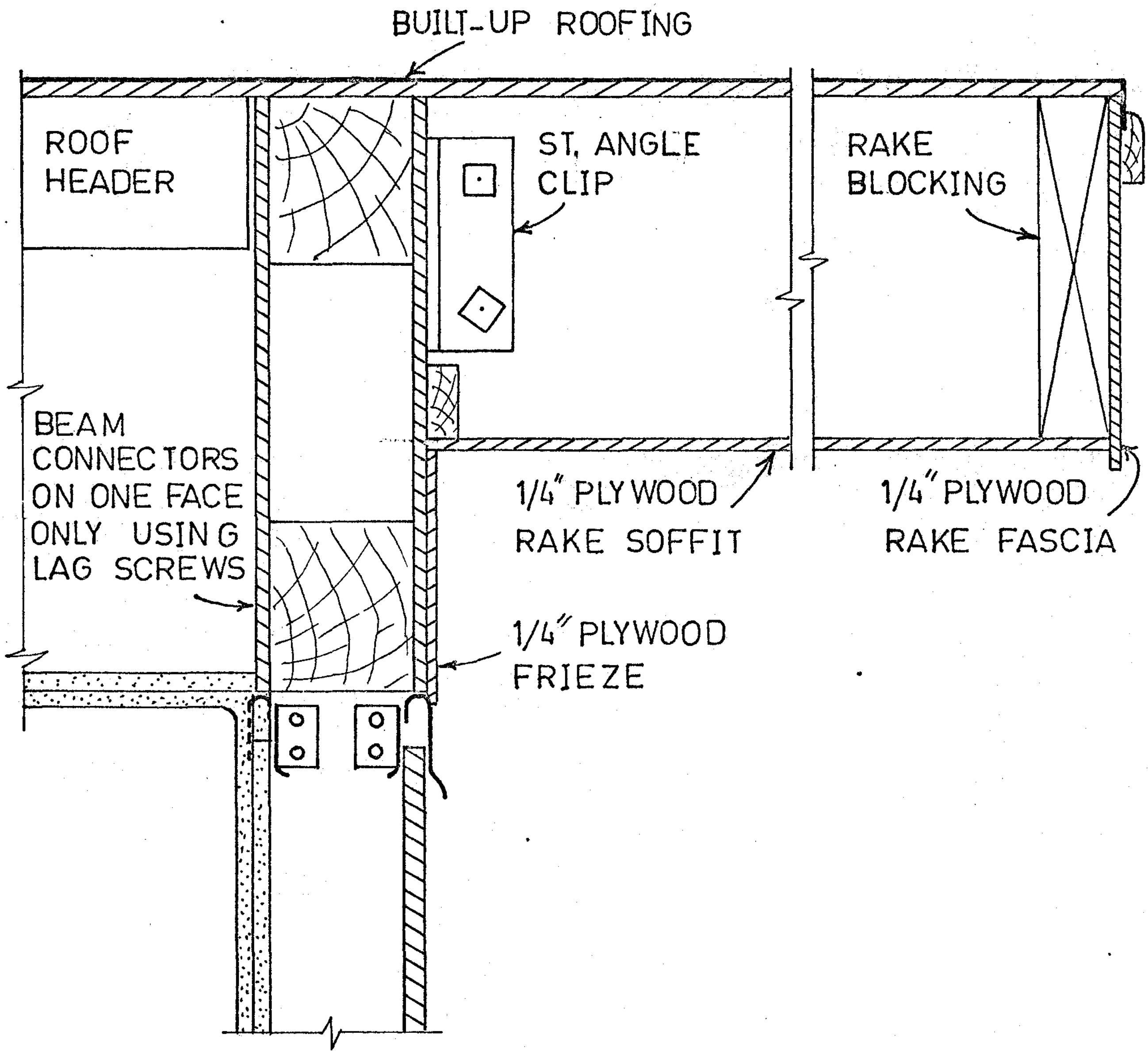


Figure: 18

SECTION SHOWING RAKE DETAILS

SCALE 1:4

3.11 ARCHWAY GIRDER:

A three module span archway girder will be necessary for L-shaped living-dining room and similar arrangements. This girder will be 4" x 12" wood supported by extra posts at each end. This is illustrated in Figure 19.

3.12 CLOSETS, SHELVES AND CUPBOARDS:

Closets provide an important source of increased flexibility if they are built as self-contained units or storage walls which need not be aligned with the modular grid. This is suggested in Figure 20. They would consist, of course, of prefabricated units.

It is now common practice to prefabricate kitchen cupboards, and this would fit well into the present scheme.

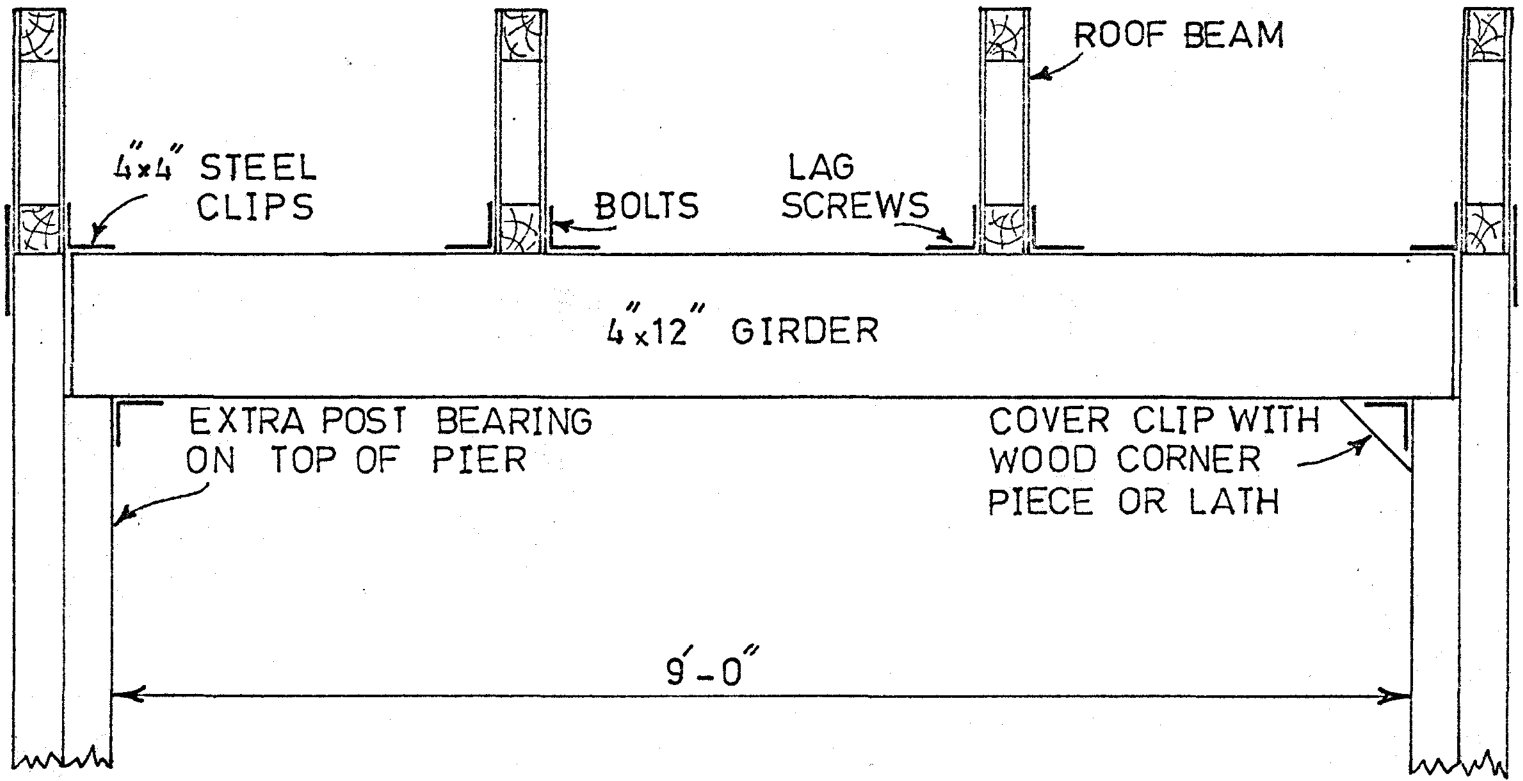
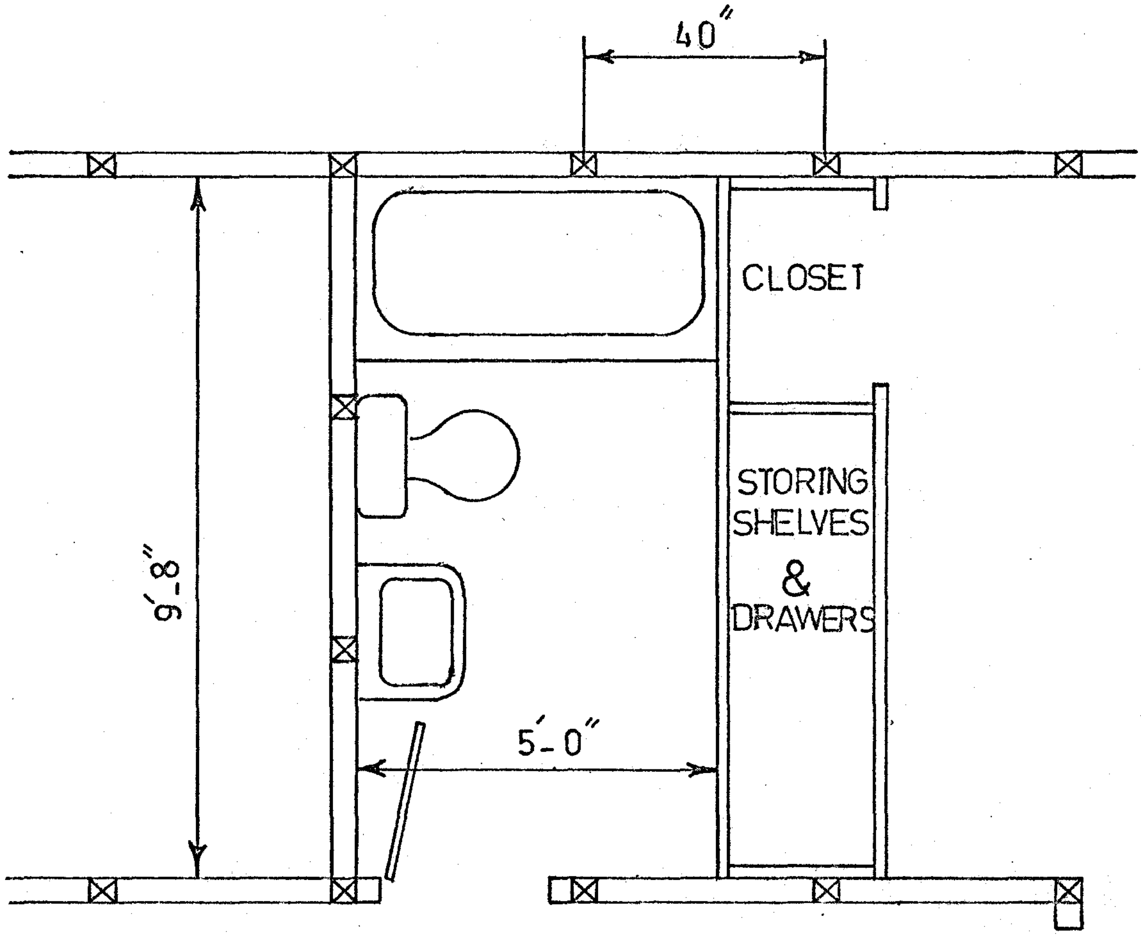


Figure: 19

ELEVATION SHOWING ARCHWAY STRUCTURE

SCALE 1:16



PLAN ILLUSTRATING PLANNING FLEXIBILITY WITH STORAGE WALLS

Figure: 20

SCALE 1:32

3.13 PLUMBING:

The basic bathroom is shown in Figure 21. However, many other variations are possible. Plumbing should be adaptable to standardization and factory sub-assemblies. For example, roughing in assemblies for each fixture could be provided that would be self-contained units bolted to posts. Connections would be made to floor water pipes and drains and to fixture pipes. The open frame carrying this would also support fixtures.

In most cases, it will not be possible to combine vents of different fixtures until they are above ceiling level, since the relatively large holes required could not be cut through posts.

3.14 HEATING:

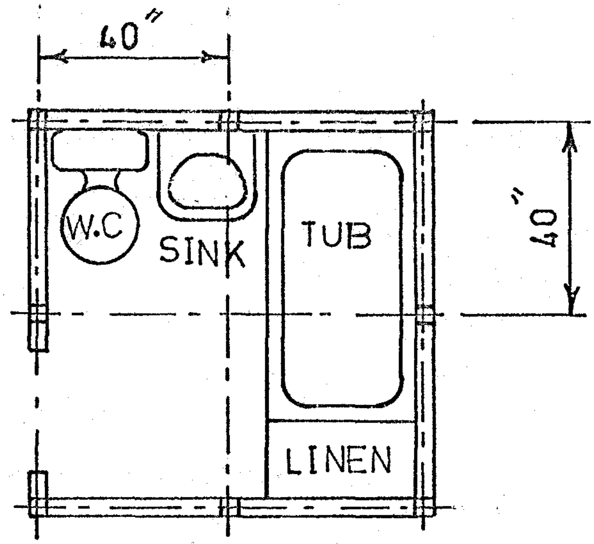
Heating would most economically be hot air perimeter heating in which warm air is carried in 8" ducts buried in the floor around the perimeter of the building. Air is released through floor registers below windows. The furnace would be a counterflow oil or gas fired unit.

Light prefabricated chimneys are available, which would be well adapted to this type of construction. This is shown in Figure 22.

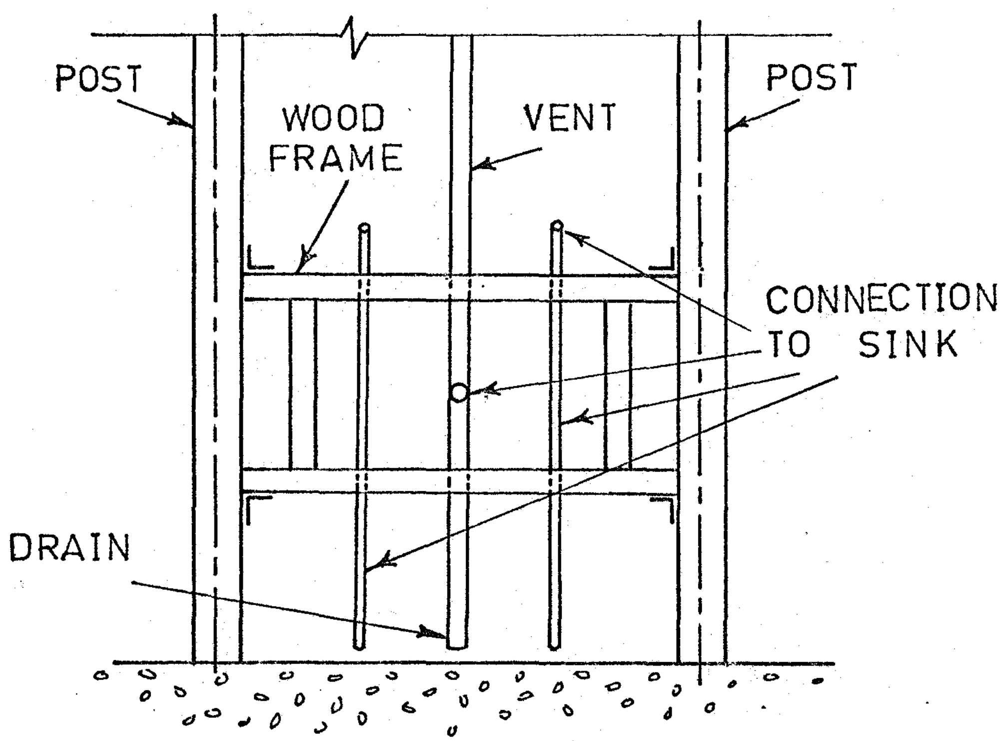
3.15 ELECTRICAL:

Electrical work would be quite conventional. Posts could all be predrilled for passage of wiring.

Special wall and ceiling panels would be provided with outlet and fixture holes.



MINIMUM BATHROOM



PLUMBING ROUGHING-IN SUB-ASSEMBLY

Figure: 21

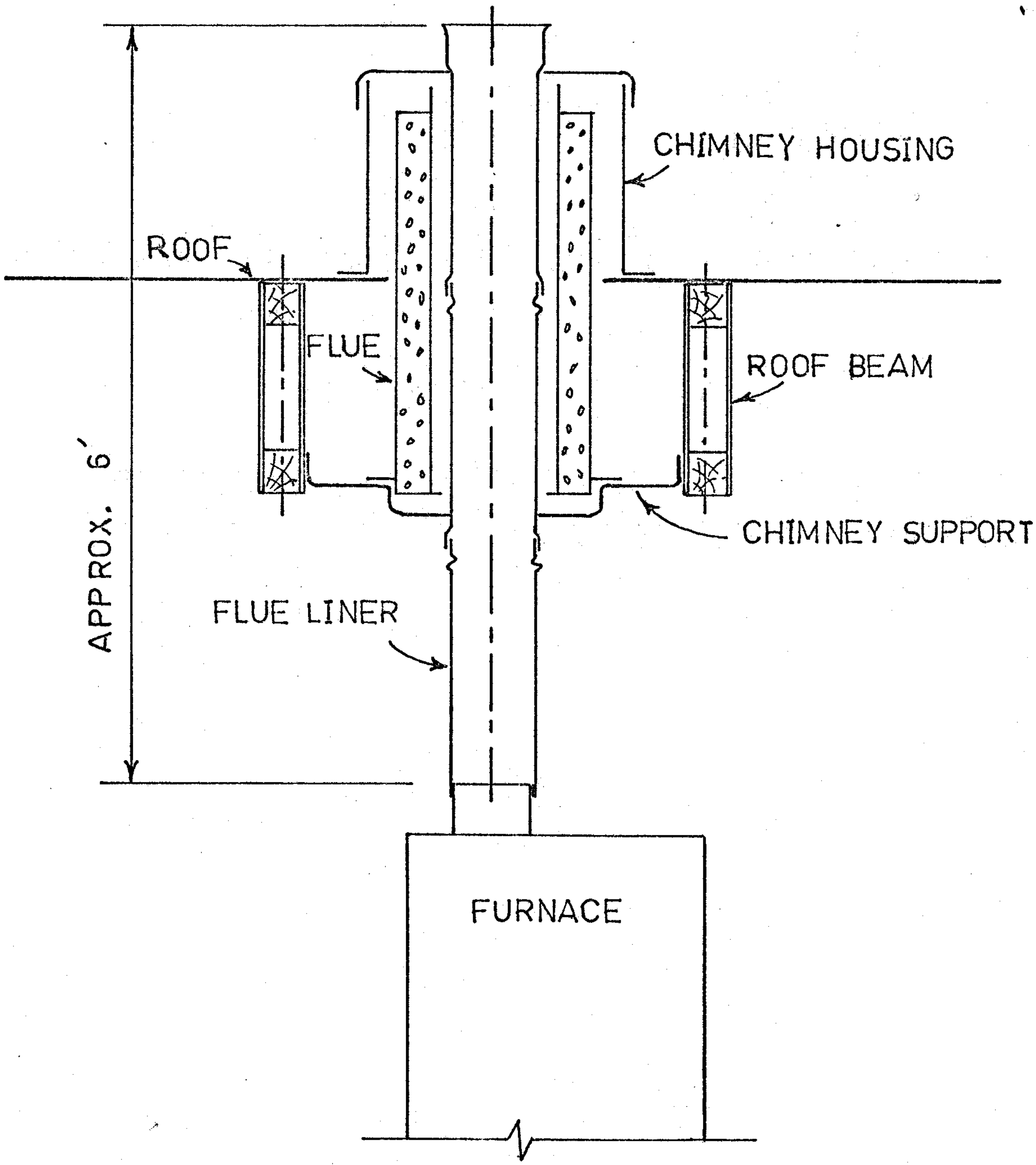


Figure: 22

ELEVATION OF PREFABRICATED CHIMNEY

SCALE 1:16

3.16 JOINTS:

Special attention must be given to the different types of joints between different parts to avoid the existence of weak points, which behave in a less uniformly strong manner than the prefabricated parts.

1. In-site concrete joints are used in the foundation and between posts and piers; this tying element should be as good and strong as the prefabricated parts.
2. If the house will consist of more than one storey, it is advantageous to cut the posts in lengths of two or three storeys, which reduces handling, positioning, levelling, and also takes full advantage of the crane-lifting capacity available.
3. Whenever bolts or screws are used for connecting different parts, attention must be given to the loads to which they are subjected and ensure that they are capable of transmitting them.

3.17 ERECTION:

The erection procedure would probably be something as follows:

1. Grade and dig trench for ground wall and holes for piers and footings.
2. Pour concrete footings.
3. Set up piers and ground wall.
4. Set up posts. Fixtures would be used to ensure accurate location and height of posts.
5. Pour concrete floor.
6. Erect roof beams.
7. Insert roof headers and eave blocking.
8. Apply roof sheathing and roofing.

9. Put on ceiling panels, soffits and fascia.
10. Install all caps, sills and clips.
11. Install furnace, bathtub and rough in plumbing and wiring.
12. Insert all exterior panels.
13. Install door and window units and exterior panels below windows.
14. Install exterior trim.
15. Install cupboards, closets, etc.
16. Lay finish floor.
17. Insert interior panels and plaster.
18. Install plumbing and light fixtures.

3.18 DEVELOPMENT:

The development stages of a scheme such as suggested above might be as follows:

1. Build panel mock ups, test roof beam prototypes and in general check individual components as much as possible.
2. Build a test cell, say, four modules by five modules (13'4" x 16'8").
3. Build a test house.
4. Secure N.H.A. acceptance.
5. Build a pilot project of 20 or 30 houses, partially for development purposes, but primarily for promotion.

CHAPTER IV
THE SPACE ALLOCATION PROBLEM

4.1 DEFINITION OF THE PLAN LAYOUT PROBLEM:

The effectiveness of a certain layout results from correct grouping of organizational unit task areas into activity areas, efficient utilization of space within each activity area, provision of adequate space for circulation paths between activity areas and correct choice of location for each activity area. The last item is related to the plan layout problem. Thomas Anderson defines it as follows:

> "Given certain building activities and their areas, "optimum" solutions of locating these activities can be found by considering certain criteria."

The "optimum" solutions produced by systematic procedures based on a certain criterion will almost invariably conflict in some manner with the "optimum" solutions generated by other systematic procedures based on some other criteria. Total optimization would require evaluation of an alternative list L_{ij}, where i is one of the systematic procedures [i = 1, ..., n] and j is one of many possible alternatives generated by each procedure [j = 1, ..., m] (3, p.9.). In addition, total optimization assumes that all alternatives can be evaluated in terms of a common measure of performance. For this reason, "optimum" solution means the most satisfactory solution generated by the systematic procedure based on the assumed criteria.

4.2 THE NEED FOR SPACE ALLOCATION STUDY:

The architect usually designs buildings by the intuitive method; design by experience, knowledge, and tradition. The architect is ever mindful of structural, functional, and aesthetic requirements of the project with which he is concerned, but the burden of maintaining the overall idea of the building's concept, while developing the smallest details of the design, is becoming increasingly heavy. As a result, the architects and engineers have devised many tools to ease their task, such as construction catalogues, product catalogues, and many other texts which provide the designer with listing of material and product specifications, standardized space requirements for different purposes, and information about colours, sizes, and installation methods. These devices are aids which enhance and insure the success of the architect in the design process. The services available through systems analysis in the area of space allocation are also aids to the architect in fulfilling his obligation to produce good functional buildings. Just as architects cannot keep in mind the many materials and products available for his use, neither can he be expected to analyze and remember all of the possible solutions for providing a functional layout.

The systems analysis approach as applied to the problem of functional space allocation provides the architect with a diagramatic layout of a good or even the best schematic solution. The technique does not dictate the final design, for it is the designer's job to transform the diagram into a working floor plan.

For the client, the advantages of providing the best functional solution are numerous. The reduction of movement by personnel or materials will increase the time available to be spent in productive effort, and reduces the cost of transportation for materials.

These techniques not only provide an initial floor plan layout, but also helps in re-allocation of space as functional relationships change with time.

The concept of modern architecture was established on the premise that the external aesthetic expression of a building or group of buildings should reflect its internal, functional requirements, that is, the form should follow the function, but the internal, functional relationship may change with time, and, in many cases, the entire function changes. Surely excellence in design must attempt to anticipate future changes in internal functional relationships. Space allocation techniques, coupled with the increased internal building flexibility using the previously proposed system of building, would insure greater functional efficiency and a more dynamic approach to the practice of architecture.

4.3 REVIEW OF THE EXISTING SPACE ALLOCATION TECHNIQUES:

A new exciting approach to architecture was born as a result of the industrial revolution after the First World War, which initiated the concept of building form and functional compatibility. Now we are well into another revolution, the technological revolution. One result of this revolution is the development of the computer technology which, when applied, reduces a great amount of manual repetitive effort. The program presented in this thesis will illustrate one way in which the architectural designer can use technology as a physical part of his daily practice, and eliminate many of the time consuming tasks of the building design process while achieving far better results.

Since the period immediately following the Second World War, the development of operations research (system analysis) and computer sciences have provided an entirely new approach for problem analysis and solution. Authur Hall defined a system in his book, "A Methodology for System Engineering" as a group of items with relationships between the items and their characteristics. Considering the space allocation problem, the items will be the locations and the functions to fill it, and the characteristics are the center distance that separates the different locations and the closeness rating values that are associated with pairs of functions, or the circulation cost between these functions.

The complexity and highly combinatorial nature of the space allocation problem has stimulated a diversity of solution techniques. All of those techniques seek to provide better functional solutions than the designer could obtain utilizing the intuitive approach. In the following pages there will be a brief description of the major methods that are being used. As detailed information about those methods are already published, the evaluation of the methods and advantages and disadvantages of each are briefly discussed.

4.3.1 <u>The Assignment Technique</u>

The technique of using linear programming for providing functional building layouts, by formulating the space allocation problem as an assignment problem and utilizing the transportation algorithm as a solving method, is attributed to Lynn Mosely (15). The technique can be illustrated as follows: There are (n) functions which must be placed in (n) available locations. The objective is to minimize totally the cost of assigning accommodation units to the available locations. This technique provides an accurate schematic diagram of the relative positions in which each function should be located with respect to the amount of internal and external trip generation, but when the architectural layout is developed, some key functional relationships may have to be re-established.

The formulation of B. Whitehead and M. Z. Eldars (23), breaks down each function into unit elements and the grid plan of available locations is also made up of an equal number of unit elements. It establishes an order of importance in which units of functions are located in the plan, (rather than using the simplifying assumptions of Mosely which facilitated the use of linear programming in finding the optimum location of each function), then it calculates the cost of each possible location for each unit of the different functions and selects the location which represents the minimum cost. The almost one-to-one correspondence of functions to locations used by Mosely significantly reduces the transformation task of the schematic plan to a final architectural solution.

This technique of considering a cost of assigning a unit of accommodation to a location is not suitable for house design.

4.3.2 The Additive Element Technique

This technique, formulated by B. Whitehead and M. Z. Eldars is a heuristic method which is a very straightforward procedure with an excellent computer application structure.

After establishing an order of importance in which the functions will be located in the plan layout, the areas associated with each function are then broken down into unit elements of equal suitable size. Next, one unit element of the first function in the order is prelocated on a grid of squares, with each square representing a unit element. Then, the remaining unit elements are one by one placed on the grid. The placement is determined by testing each unoccupied location on the grid adjacent to each occupied location by calculating the value of a certain selected criterion, such as the circulation cost or the closeness ratings, relating the incoming unit element and the previously located unit elements. The incoming unit element is then placed in that square on the grid which optimizes the value of that criterion. This process is continued until all unit elements are located on the grid.

When applying this technique, usually corridors or passage ways are not considered as individual functions or rooms; and, therefore, some appropriate additional square footage must be temporarily assigned to each function to compensate for corridor space. When the diagramatic solution is transferred into a real layout, this space will be removed from each function when the corridors are incorporated into the final floor plan.

Applying this technique any function or room can expand to any shape having an area equal to that specified for this particular room. This makes the job of the architect or the designer more difficult when transforming the diagramatic plan into an architectural one. For this reason this technique will not be used in designing houses.

When utilizing the technique for the arrangement of an existing plan, fragmentation may occur due to the restrictions on the available layout area, and must, of course, be corrected when making the transformation to the working floor plan. When applying the technique for the design of a new facility with no building configuration, fragmentation never occurs, as the grid size is much larger than required to locate all the unit elements.

4.3.3 The Interchange Technique

The process is carried out by analyzing a given solution for possible improvement by determining the reduction in the value of the selected decision criterion, that would occur if two or three functions were to exchange locations. The method requires that an initial solution be provided by the user, along with all pieces of information corresponding to the decision criterion. This technique is not capable of tackling the design of a new building without existing configuration and therefore is not suitable for designing houses.

The craft method devised by Elwood S. Buffa and Gordon J. Armour (5) using this technique has gained wide acceptance by industry for the allocation of inter-plant departments, in order to minimize the circulation cost within the plant.

In order for two or three functions to be considered for possible exchange, one of the following three conditions must be satisfied:

(a) The functions must be the same size,

(b) They must have a common border,

(c) They must border on a common third function.

The exchange mechanism is carried out in the following manner:

The technique can either exchange entire functions if they are of the same size and shape, or if they are not of equal size, it can groove space out of the larger function to make room for the smaller functions, if an exchange of this type is favourable. The user can specify the type of function exchanges desired, two way, three way, or the best of either. After the exchange is made, the process is continued by scanning the updated layout for possible improvement, until no further favourable exchanges are found.

4.3.4 Vector Analysis Technique

Wheeler and Miller (22) developed this method of analyzing human interaction among activity areas in a building. The object is to produce a plot in which each area is represented by a point. The length of the lines (links) between activity areas (points) indicates the strength of interaction between the activity areas. The strongly interacting activity areas locate close to each other. This method merely solves for coordinate points which minimize the function

$$\phi = \sum_i \sum_j W_{ij}(Z_{iK} - Z_{jK})2$$

where

W_{ij} = interaction between activity areas i and j

= (importance) x (frequency) of interaction

Z = coordinates of i and j

K = 1 for x coordinates

K = 2 for y coordinates of the point

$(Z_{iK} - Z_{jK})2$ = the squared distance separating the two points i and j

A triangular plot is set up in advance by arbitrarily establishing locations for the three activity areas which have minimum interactions with all other activity areas and some interactions with each other. All other points are determined by solving the previous equation and fall within this triangular area. The result of the computation reveals that activity areas with strong interactions are grouped so close together in the center of the plot that it is difficult to see the amount of interactions. Consequently, the determination of how the activity areas should be located spatially is difficult to make.

The vector analysis method does not take area and shape of activity area into consideration. It is extremely limited as a plan layout method, therefore it is not suitable for designing houses.

4.3.5 Random Technique

This method was advised by David Parsons (18). This technique considers thousands of layout possibilities, scores each one according to the matrix of interorganization location preferences. The mathematical process used to determine the locations of the different functions is the random numbers or Monte Carlo technique. The scoring process could be illustrated as follows: If element A and B are 5 squares apart and the strength of their relationship is 6, the score is then 5 x 6 = 30. The total score for a particular layout is obtained by summing the scores of all other pairs of elements. If a new arrangement is better than the old, it will be held in the computer's memory; if it is worse this change will be neglected.

This technique does not take area and shape of elements into consideration and for any fair size building the number of selections or possibilities examined may run extremely high, resulting in the consumption of excessive computation time, and money. It also suffers from the problems of gaps and overlaps in the resulting layouts, which makes the adjustment effort more difficult. For all these reasons this technique is not suitable for designing houses.

4.3.6 Clustering Technique

This method makes use of the fact that a design problem can be decomposed according to its requirements. In the HIDCES approach (HIerarchical DEComposition of Systems) developed by Christopher Alexander (1),(2), the design problem is subdivided into smaller problems by identifying subsets of design requirements that interact highly among themselves and minimally with the requirements in other subsets, then, each subset of requirements is supposed to lead to some subcomponent of the completed design.

This method mainly selects and combines the appropriate two elements which have the highest coherency value, in order to produce the most highly interconnected subset. Then, it identifies the two subsets involved, and issues a new identification number to this subset, removes the two original subsets, adds the new subset and recomputes coherency values for the new list of subsets. The process continues until a hierarchical tree is computed and one final set remains representing the final diagramatic plan layout.

Further work was done by Bierstone, E. and Bernholtz, A. (7). In this method the system of elements and interactions defines a linear graph, of which the elements are vertices, and the interactions non-directional lines joining pairs of vertices.

I do not have enough information to evaluate this technique and its effectiveness in layout planning.

The techniques discussed so far are the techniques used in determining the final plan layout using certain decision criterion. The two most commonly used criteria are as follows:

4.4 DECISION CRITERION:

4.4.1 The Cost Concept

The object of this concept is to minimize the circulation cost of both material and personnel taking into consideration the number of trips generated between the different functions, the traffic intensity, the cost of transporting different materials and goods per unit distance, the salaries of the staff members and the distances between the different functions.

It is very important to follow this concept when planning factories, hospitals, office buildings, industrial buildings, or any similar type of buildings which have a great amount of material flow or personnel movement, or both.

The reduction of movement by personnel or materials will increase the amount of time available to be spent in the productive effort, and for material movements, the cost of interplant transportation will be reduced.

4.4.2 The Neighbouring Concept

There are some buildings as museums, houses, art galleries, ..., etc., which have a totally different criterion for allocation of functions. Since the reduction of circulation is not of primary importance, the use of the minimum circulation cost concept may not be applicable.

In these cases the architect or the user must supply values that represent how they feel elements should ideally relate to each other; in other words, they should specify the closeness rating for each pair of elements as input data. Then, an order of importance is to be established so that the function listed first is that room which has the greatest relations with all the other functions, the second function in the order is the function which has the strongest relations with the first function, the function listed third is which has the strongest relations with the previously ordered functions. The process is carried out until the sequence is completed. The functions then are to be located on the grid so as to achieve maximum satisfaction for the previously specified closeness ratings.

Once the architect or the user knows the limitations and abilities of each technique, he can more adequately select an applicable, desirable, and economically feasible technique to solve the given problem.

After the schematic solution is developed by the technique, it is necessary to determine what considerations and knowledge are required in order to obtain a final architectural floor plan which exploits the work done by the techniques.

CHAPTER V

COMPUTERIZATION OF THE HOUSE PLAN LAYOUT

5.1 INTRODUCTION:

The purpose of this chapter is to present a proposal for using a modified space allocation techniques in designing a house plan, and to explain the computer program to accomplish this task. A vivid representation of the inter-relationships between the different rooms in the form of a block layout is produced.

As a result of the previous study of the existing space allocation techniques, it was felt that the emphasis should be placed on the relationships and closeness ratings between the different rooms as the basic criterion for layout arrangement. There are several reasons supporting this decision.

First, the number of persons occupying a certain house is relatively small, and consequently any quantitative analysis of flow of personnel or materials within a house will yield trivial results and will not provide a sufficient basis for a layout.

Second, there are numerous other considerations that a pure flow analysis might ignore, while the relationship method is easiest to illustrate. It is quite clear that there are some rooms where you can find noise, dirt, fumes, and interruptions such as the kitchen, laundry, ..., etc. A layout based on flow analysis might place these rooms in the vicinity of the clean, quiet rooms.

Third, a very effective, and probably the best way of reflecting the user's preferences for the relationships and closeness of the rooms, is to use a Relationship Chart. It was first advised by Richard Muther (16) [See Appendix B for an explanation of using the Relationship Chart]. The chart itself is nearly self-explanatory. Each pair of rooms must be considered and the appropriate value of closeness placed in the box common to both rooms.

Several trials were done to find out the number of closeness ratings and the appropriate distribution of these ratings, so as to achieve good representation of the corresponding relationship requirements in the final block layout of a house. The present system has six ranks of positive attraction, as follows:

Value	Closeness
12	Absolutely Necessary
10	Especially Important
8	Important
6	Ordinary Close
4	Unimportant
1	Undesirable

FIGURE 23: Closeness Ratings Values

The technique used in this thesis to place the rooms in the layout could be called "An Additive Function Technique" (where the function here means a room) rather than an additive element technique. It treats each room as one undivided unit. The length and width of each room is taken as a whole multiple of the module (40"). The rooms are placed one by one on the plan layout grid using the weighted center distance between the different pairs of rooms as a decision criterion. The whole process will be explained in detail later on in this chapter.

The value of using a computer to analyze the relationships and produce a block layout can be better appreciated when we note the number of possible inter-relationships between the rooms. In a simple problem consisting of seven, there are $(n^2 - n) / 2 = 21$ inter-relationship and a $n! = 5040$ possible layout. If the number of rooms is 12, there will be 66 inter-relationship and $479{,}001{,}600 = 47.9 \times 10^7$ possible layout. The architect cannot be expected to analyze and remember all of the possible solutions for providing a good functional layout; also it is not economically feasible to consider even a fraction of these possible layouts manually. For this reason an exhaustive search is impractical even when using a computer. This indicates the need for some sort of heuristic, systematic search technique, as in the present program, to allocate the resources of computer time and space in as efficient a way as possible to produce a high likelihood of coming up with an optimum design solution.

The very important problem of layout planning in general could be solved by a combination of the following tools:

1. Relationship Charts developed with the appropriate representative of the house to be planned.
2. Developing the modular areas required for each room.
3. Specifying the exposure directions required by the user.
4. Analyzing the Relationship Charts, in view of the previous requirements,

in a logical manner with a computer.

5. Developing the optimum plan layout satisfying all the previous requirements with a computer.

5.2 CAPABILITIES:

The program presented in this thesis for Optimum Computerized REłationship Plan Layout, OCREPL, is a very good method for layout planning using the Relationship Charts.

In its present configuration it can effectively do the following:

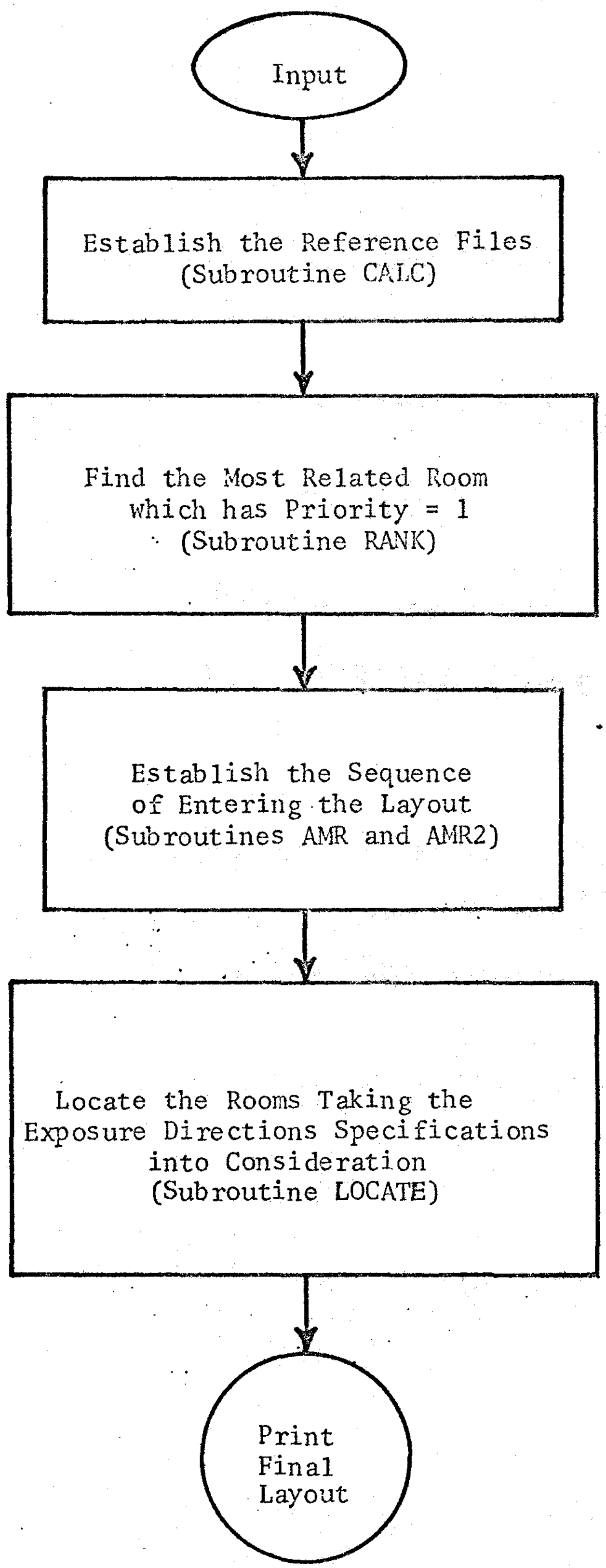
1. Determine the nearest modular area and dimensions of each room to the area and dimensions given by the user as input data.
2. Analyze a Relationship Chart of any size and establish the relationship matrix.
3. Establish an order of importance according to which the rooms will enter the layout.
4. Produce an optimum block layout minimizing the sum of the weighted center distances between all the rooms, maximizing the satisfaction of the required relationships, satisfying the user's specifications for the exposure directions of the different rooms, taking into consideration the previous analysis of the room's shape and area and the given relationships between the different rooms.
5. Print out the intermediate plan layouts, if desired, in a matrix format with each element in the layout matrix representing one modular unit (40" x 40") and with each room identified by its number.
6. Print out the final plan layout in a matrix format and provide as well a plotting on the graph plotter showing the contour of each room and identifying the rooms by its name rather than its number. An extra sheet divided into modular units is provided to help the

user in transforming his computerized house plan into a working plan layout.

Although this program is used here in designing houses, it is capable of producing any plan layout for any kind of buildings, industrial, commercial, institutional, applying either the relationship and neighbouring concept or the circulation cost concept as a decision criterion.

chart 1:

General Flow Chart for OCREPL



5.3 METHODOLOGY:

5.3.1 General

In this detailed explanation of the actual program, use of the FORTRAN IV Language is avoided whenever possible, and the discussion is restricted to the present program as written and used on the CDC 6400.

The discussion explains in detail each subroutine in the same sequence that they are used in the program, including the necessary flow charts (understanding of the charts will be assisted by reference to Appendix A).

The subroutines called by OCREPL are CALC, RANK, AMR, AMR2, LOCATE, PLAN1, PLAN2 & PLAN3. A complete listing of the program can be found in Appendix D.

5.3.2 Input

The required input data consists of the following:

UNAME	=	user's name	
XY	=	land length	arbitrary
YL	=	land width	
N	=	number of rooms	
NN	=	$(N^2 - N)/2$	
I	=	room number (going from 1 to N)	
XNAME(I)	=	name of the ith room	
X(I)	=	the length of the ith room (ft.)	arbitrary
Y(I)	=	the width of the ith room (ft.)	
A(I)	=	the area of the ith room (ft.^{2})	
IDRC1(I)	=	the first exposure direction of the ith room	

IDRC2(I) = the second exposure direction of the ith room

IWAIT(NN) = vector representing the closeness ratings in only one half of the Relationship Chart (see Appendix C for the sequence of writing the closeness ratings).

All input data is printed out, if wanted, at the beginning of the program to provide a convenient check on the accuracy of the keypunching, presence of all pieces of information required and the completeness of the card reader. Figure 24 is an example of this check.

5.3.3. Reference Files

Before the Relationship Chart can be analyzed, a set of reference files must be established.

A. Determining the dimensions of the rooms in modular units

There are two cases, the first case when the area only is specified, and the second case when a given length or width or both are specified together within the area. In both cases the nearest modular dimensions and area to the specified ones are selected. Chart 2 will explain this.

B. Establishing the size of the layout matrix

First, if there is no restriction on the building configuration, i.e., XL and YL are not given, the program will establish an adequate size of the layout matrix. It was found that a square matrix, with side size equal to three quarters of the summation of the computed modular length of all the rooms, will be suitable for the location process, but this does not mean that the final layout

OPTIMUM PLAN LAYOUT USING THE NEGHBOURING TECHNIQUE

****

NUMBER OF ROOMS TO BE LOCATED..................N = 9

LAND LENGTH...................................XL = 0.000 FEET

LAND WIDTH....................................YL = 0.000 FEET

INITIAL SPATIAL CONFIGURATION OF EACH ROOM

NO.	NAME	LENGTH(FEET)	WIDTH(FEET)	AREA	EXPOSURE	DIRECTION
1	BED 1	10.00	10.00	100.00	0	0
2	BED 2	10.00	10.00	100.00	0	0
3	BED 3	10.00	10.00	100.00	0	0
4	BATH 1	0.00	10.00	65.00	0	0
5	BATH 2	0.00	10.00	65.00	0	0
6	LIVING	20.00	10.00	200.00	0	0
7	DINNING	10.00	10.00	100.00	0	0
8	KITCHEN	10.00	10.00	100.00	0	0
9	GARAGE	17.00	10.00	170.00	0	0

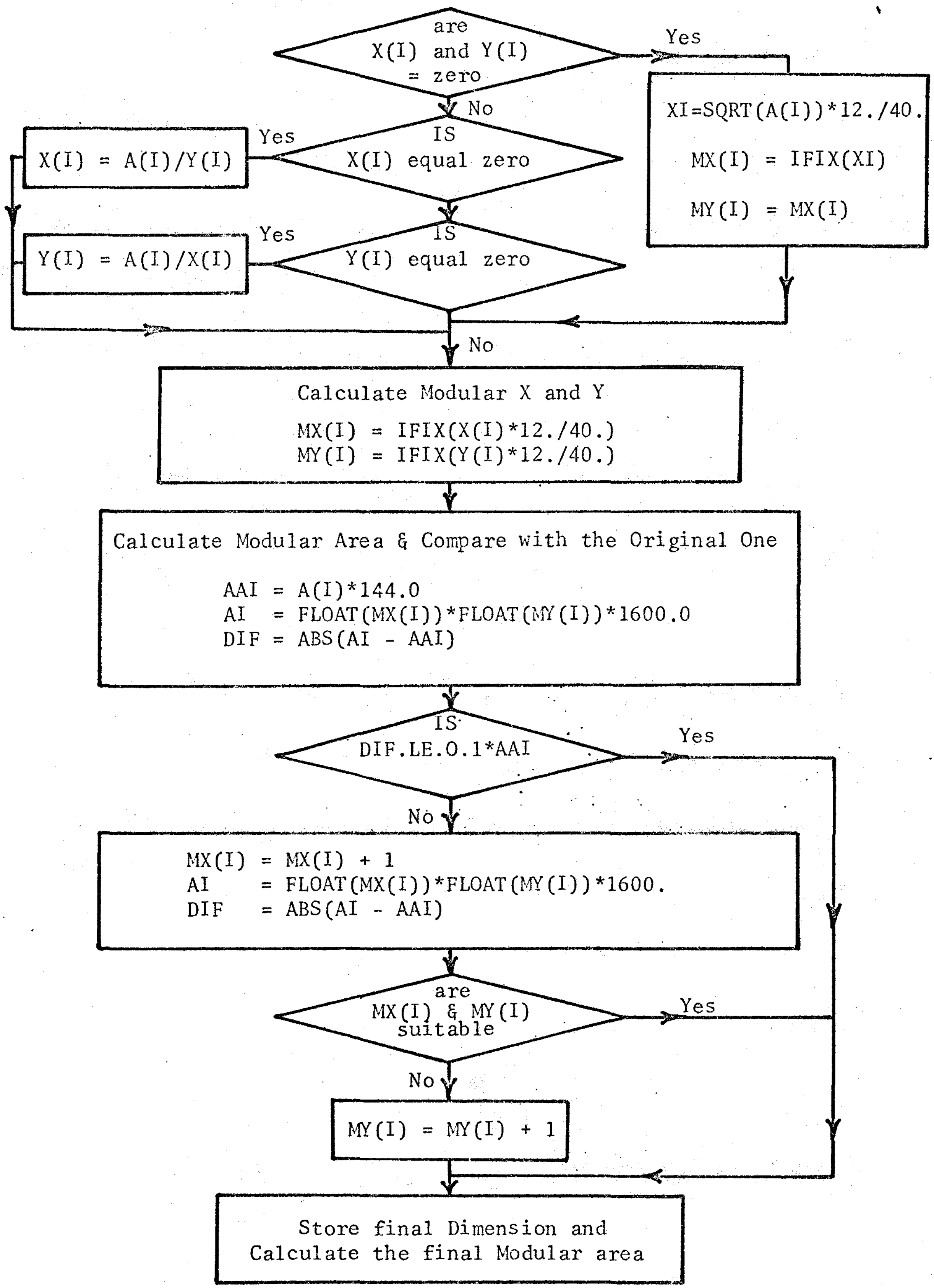
THE RELATIONSHIP CHART

	1	2	3	4	5	6	7	8	9
1									
2	10								
3	6	12							
4	12	12	4						
5	1	4	12	4					
6	12	4	4	6	1				
7	4	6	6	4	6	12			
8	1	1	1	1	4	12	12		
9	1	1	1	1	1	4	12	12	

Figure: 24

chart 2:

DETERMINING MODULAR DIMENSIONS



will use all this space. It will be shown later, when discussing the exposure direction problem, that some areas of the layout matrix will be excluded in the search process to satisfy the exposure directions specifications. Secondly, if the area to be built is restricted by a given XL and YL, then the length and width of the layout matrix will be the modular units corresponding to XL and YL. Then a check is performed to ensure that the area of the layout matrix is not less than the total area of the rooms, otherwise an error message is printed out and an exit is called.

It is important to note the effect of the size of the layout matrix on the final block layout produced. If this size is big enough, this will allow a stable growth of the layout producing the optimum final plan layout, but if the size is restricted, there is no way to ensure that the produced plan is the "Absolute Optimum", it will be the "Optimum Available" with these restrictions. So, the user is encouraged to run the program once without restrictions on the land size; taking this size into consideration when specifying the rooms' size, and run it again with suitable size restrictions, if the plan produced from the first run did not fit into his land.

C. Establishing the relationship matrix

The relationship matrix is a symmetrical, square matrix of size (N x N) with all the diagonal elements equal to zero. One half of it is read as input data and the whole matrix is to be generated by symmetry. It defines the closeness values and relationships between rooms. The following figure shows an example of this matrix [CLOSE(I, J)]:

	1	2	3	4
1	0	12	12	1
2	12	0	1	(12)
3	12	1	0	12
4	1	12	12	0

FIGURE 25: Relationship Matrix

The circled element of the matrix in the row number two and the column number four, represents the relationship (closeness rating) between the two rooms 2 and 4.

D. Computing the total closeness rating for each room

The total closeness rating (TCR) for a given room is the sum of the closeness ratings of this particular room with the rest of the rooms. In other words, the summation of all the elements in a certain row (or column) represents the total closeness rating of the room corresponding to this row (or column).

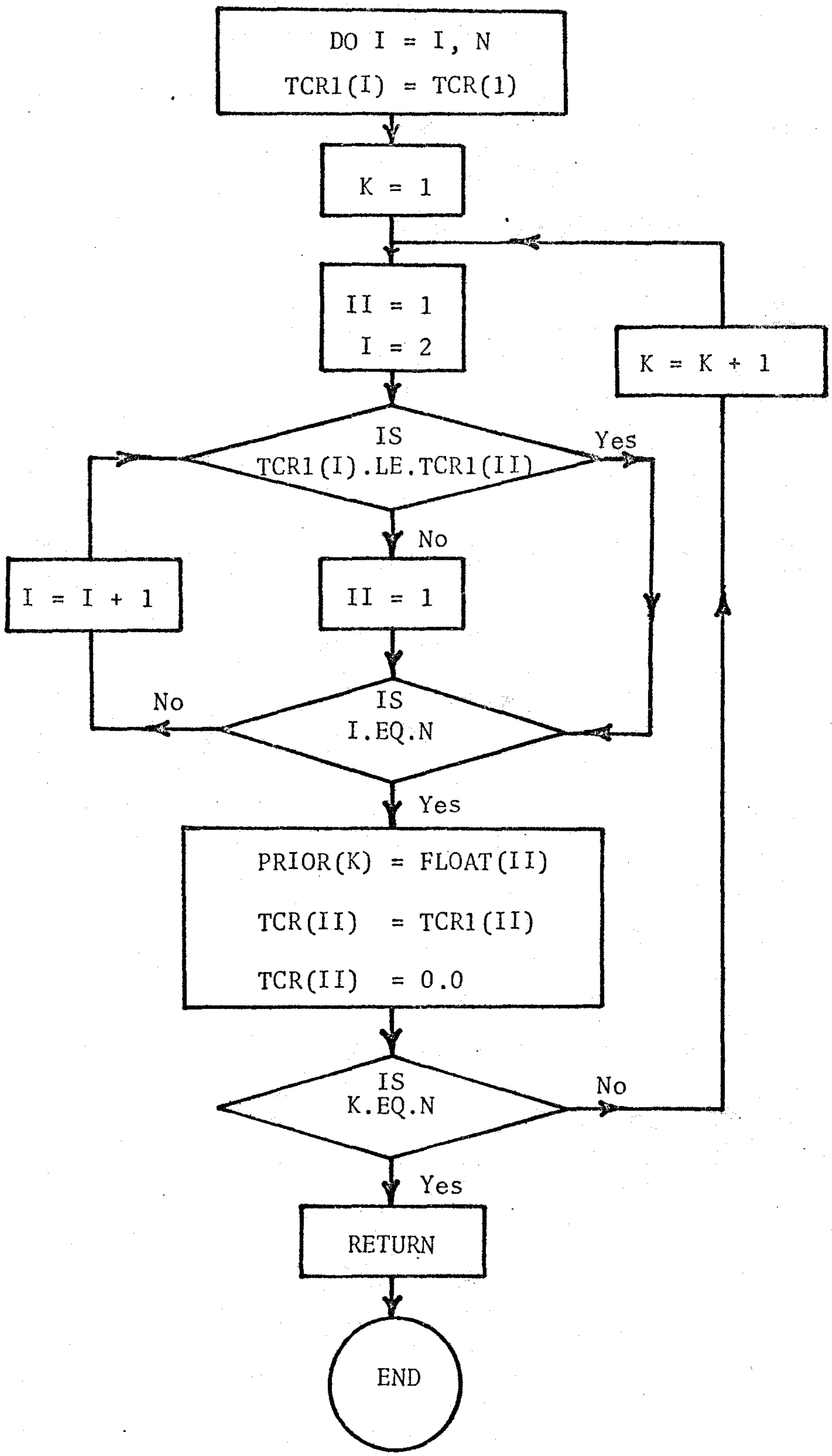
E. Ranking the different rooms according to decreasing TCR

This process is performed using subroutine RANK called from subroutine CALC. This subroutine will rank the rooms according to decreasing TCR, if two or more rooms have the same TCR, their final rank will be a function of the original order. It gives priorities to the rooms according to their position in the established order, in other words, the first room in the order will be assigned a priority equals one and the second room will have a priority equals two, and so on (see Chart 3).

chart 3:
Subroutine RANK

Input

N
TCR



Output

PRIOR
TCR

Later in the program, many searches of the relationship matrix will be made to determine the sequence in which the rooms will enter the layout matrix. It will improve the decisions made following a search, if two or more rooms are equally eligible to enter the layout, to select the room which has the highest priority (priority one is higher than priority two).

5.3.4 Establishing the Sequence in which the Rooms will Enter the Layout

A. Selection of the first WINNER

It is now possible to begin establishing a list which represents the sequence in which the rooms will enter the layout. The WINNERS are selected on a competitive basis. The selection of the first WINNER is quite simple relative to later selections. The room with the highest total closeness rating is selected as the first WINNER. This selection is the best in most cases as it puts the most "involved" room in the layout first, thus allowing rapid and stable growth of the layout whether it is a house layout or any other kind of building layout.

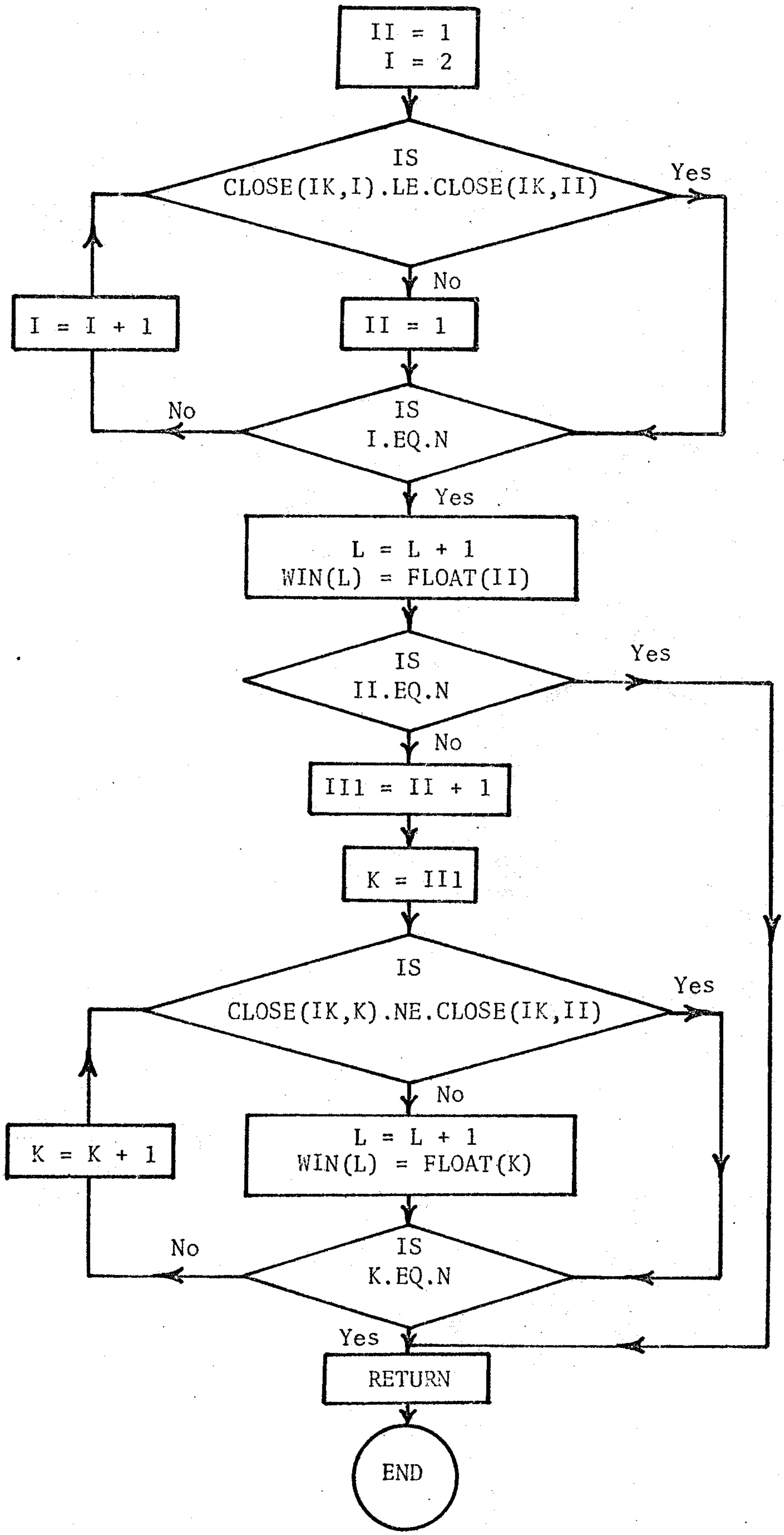
B. Determining the most related rooms to the first WINNER

The next step is to select the next rooms to enter the layout from those remaining. This is accomplished by entering the relationship matrix at the row associated with the first WINNER, reading from left to right, selecting the highest rating in this row, and obtaining the room corresponding to this rating (column number). This room is the second WINNER. The search continues in the same row and if any room (or rooms) is found to have the same rating with the first WINNER, it will be selected as the next WINNER. This is done using subroutine AMR (see chart 4).

chart 4:
Subroutine AMR

Input

CLOSE
N
I
IK



Output

WIN
L

C. <u>General selection of subsequent WINNERS</u>

The next section of the program consists of an algorithm that guides the computer in selection of rooms to enter the layout next. Before a detailed discussion is attempted a general description might be in order. Upon entering this portion of the program, at least two rooms are already selected.

The existing WINNERS are considered as one unit, their relationships with the remaining rooms are added up to produce one row matrix [TOTAL(I)] which represents the closeness ratings between all the previously selected WINNERS and the remaining rooms. This row is analyzed to determine the room (rooms) which has the strongest relationship with the WINNERS, and select it (them) to be the next WINNER(S). This analysis is performed by subroutine AMR2 (see chart 5).

This process is continued until all the rooms are selected and a complete list of the subsequent WINNERS is produced.

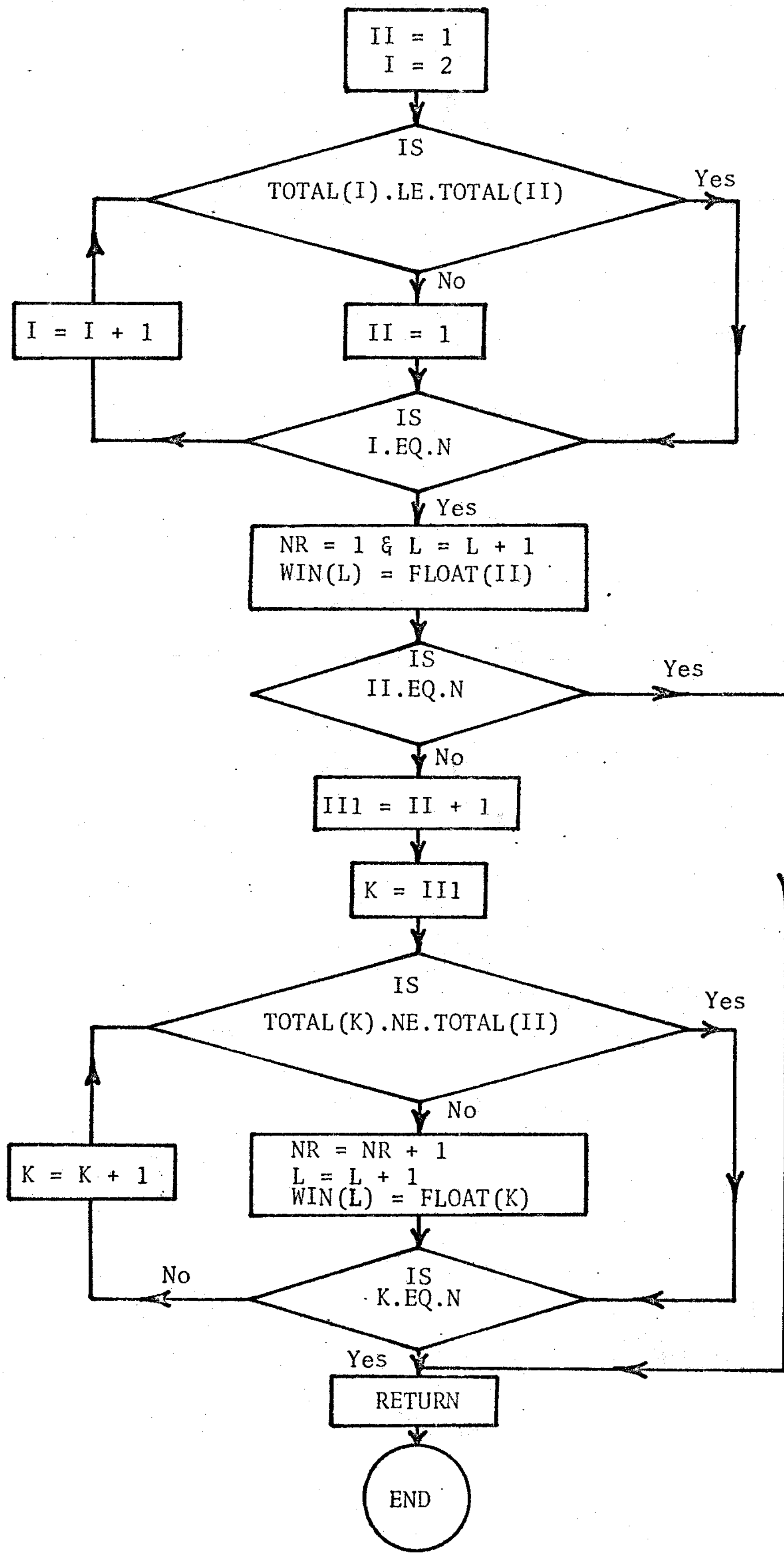
It is now possible to discuss some of the basic concepts of the general selection routine within this brief introduction. It is useful to provide an example to illustrate the process of selecting the subsequent WINNERS.

Suppose that we have a problem which consists of seven rooms having the following relationship matrix, and the rooms number two and four were selected to be the first and second WINNERS.

chart 5:
Subroutine AMR2

Input

TOTAL
N
L
NR
WIN



Output

WIN
L

	1	2	3	4	5	6	7
1	0	10	8	12	6	4	1
2	10	0	10	12	6	6	1
3	8	10	0	4	12	4	1
4	12	12	4	0	6	6	4
5	6	6	12	6	0	4	4
6	4	6	4	6	4	0	12
7	1	1	1	4	4	12	0

The vector TOTAL (I) will be the summation of the second and fourth row as follows:

1	2	3	4	5	6	7	(I)
22	12	14	12	12	12	5	TOTAL(I)

It is important to note here that it is essential to eliminate the possibility of selecting the same room as a WINNER more than once. If the program allowed repetitious selections, a great deal of confusion would take place and disturb the whole algorithm. A simple trick was established to set the value of the vector TOTAL(I) corresponding to a previously selected WINNER equal to zero, before any further analysis is performed on this vector to determine the next WINNER. Accordingly, the vector TOTAL(I) will contain the following values:

1	2	3	4	5	6	7	(I)
22	0	14	0	12	12	5	TOTAL(I)

Then using the general selection subroutine AMR2, the room number one will be selected in the first search to be the next WINNER. Using AMR2 in a second search will indicate that room number three is to be the next WINNER. In the third search AMR2 will indicate the existence of more than one higher value and the control transfers to another section of the program to take care of the equality problem.

There are two important advantages in this way of selecting more than one WINNER using one set of values of the vector TOTAL(I) according to their relationships with the previously selected WINNERS. First, it decreases the running time of the program, as the searches are more orderly and fewer searches of the relationship matrix have to be made to complete a layout. Secondly, it eliminates the rooms with very low TCR but with one high rating with a previously selected WINNER from entering the layout early. This prevents any possible restrictions of growth in that area of the layout caused by placing a room which has no further relationships at the required level to develop new WINNERS.

There are two aspects to the problem of equal relations. It may happen after selecting one or more new WINNERS (as in the previous example), in this case we neglect it and use those new WINNERS to obtain a new TOTAL(I) vector and analyze it in the same previous way. Or it takes place before any WINNER is found as a result of the search in the vector TOTAL(I), and in this case the priorities previously determined are an excellent way of breaking these ties and selecting one room from those of equal ratings which has the best priority to be the next WINNER. Then a new vector, TOTAL(I), is obtained and the process continues until a complete list of WINNERS is obtained.

The whole algorithm which selects the WINNERS and establishes their ordered list, operates in such a manner as to insure the best development of the layout in the least time.

5.3.5 Writing the Reference Files

The previously computed reference files and the sequence of WINNERS are printed out, if desired, and Figure 26 shows an example of the computer output for the reference files.

5.3.6 Placement of the Rooms in the Layout

Subroutine LOCATE called by subroutine CALC is the most interesting and important portion of the program. It places the rooms one by one, according to the previously established list of WINNERS, in the layout matrix so as to:

(a) Minimize the sum of the weighted center distance between all pairs of rooms which maximize satisfied relationships.

(b) Satisfy the specified exposure directions for different rooms.

(c) Keep the previously determined configuration and shape of each room throughout the search process.

Before discussing how this subroutine locates the rooms in the layout matrix, there are three important points to be explained. These points are the search process, the decision criteria and the exposure directions.

REFERENCE FILES

ORDERED SEQUENCE OF ROOMS ACCORDING TO DECREASING TCR

ROOM NO.	AREA	LENGTH	WIDTH	TCR
7	9	3	3	62
6	18	6	3	55
2	9	3	3	50
1	9	3	3	47
3	9	3	3	46
4	6	2	3	44
8	9	3	3	44
5	6	2	3	33
9	18	6	3	33

**NOTE BOTH LENGTH AND WIDTH ARE REPRESENTED IN MODULES
ONE MODULE = 40 INCHES

SIZE OF THE LAYOUT MATRIX

NUMBER OF ROWS = 19
NUMBER OF COLUMNS= 19

SEQUENCE OF WINNERS

NO.	ROOM NO.
1	7
2	6
3	8
4	9
5	1
6	4
7	2
8	3
9	5

Figure: 26

i The search process:

Any room entering the layout is placed at first in the upper left corner of the layout matrix, then it is moved in the J direction with a step of one unit (one module) and in the I direction with a step of one unit, (these movements are not done simultaneously) until all the available spaces (not occupied by another room) are examined (see Figure 27).

ii The decision criterion:

Each time a new room is to be located in the layout matrix, a sub-optimization problem is solved to minimize the summation of the weighted center distances between the coming room and each of the already located rooms. The optimization function U which is to be minimized is:

$$U = \sum_{J=1}^{P} CLOSE(I, J) \times CD(J)$$

where:

I = the coming room number

J = a previously located room number

P = the number of the previously located rooms

CLOSE(I, J) = closeness rating between room i and room j

CD(J) = center distance between room i and room j

The complex number representation is used to represent the position of the center of any room in a certain position relative to the origin with the real part representing the distance between the center and the origin in X direction and the imaginary part representing the distance between the center and the origin in Y direction. Then

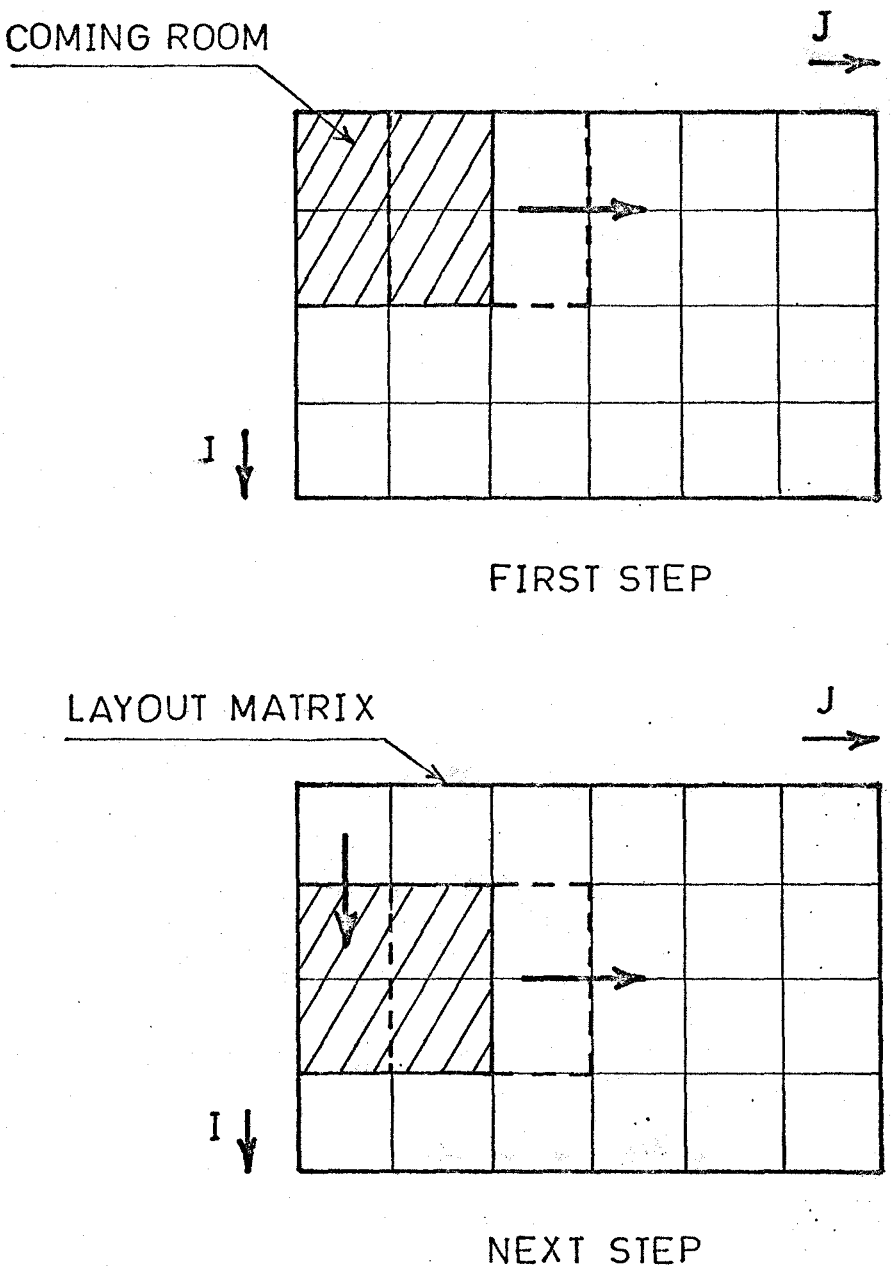


Figure 27:
THE SEARCH METHOD

we can say that:

CG[I] = CMPLX[CX, CY]

where

CG(I) = center of the room number I

CX = the real part

CY = the imaginary part,

and the center distance between a coming room (number three in Figure 28) and room number one is simply the absolute value of the difference between the two centers as follows:

CD(1) = CABS[CG(1) - CG(3)]

The physical meaning of this process could be explained as follows:

For any room entering the plan layout, there will be a number of unseen forces (see Figure 28) pulling the coming room to the previously located rooms. These forces will be proportional to the center distance separating the coming room and the previously located room. We can say that:

The pulling force = center distance between two rooms x closeness rating between the two rooms.

The room to be located is tried in all of the available spaces and is placed finally in the position which represents the equilibrium state of the whole unit with minimum internal forces, i.e. minimum weighted center distances.

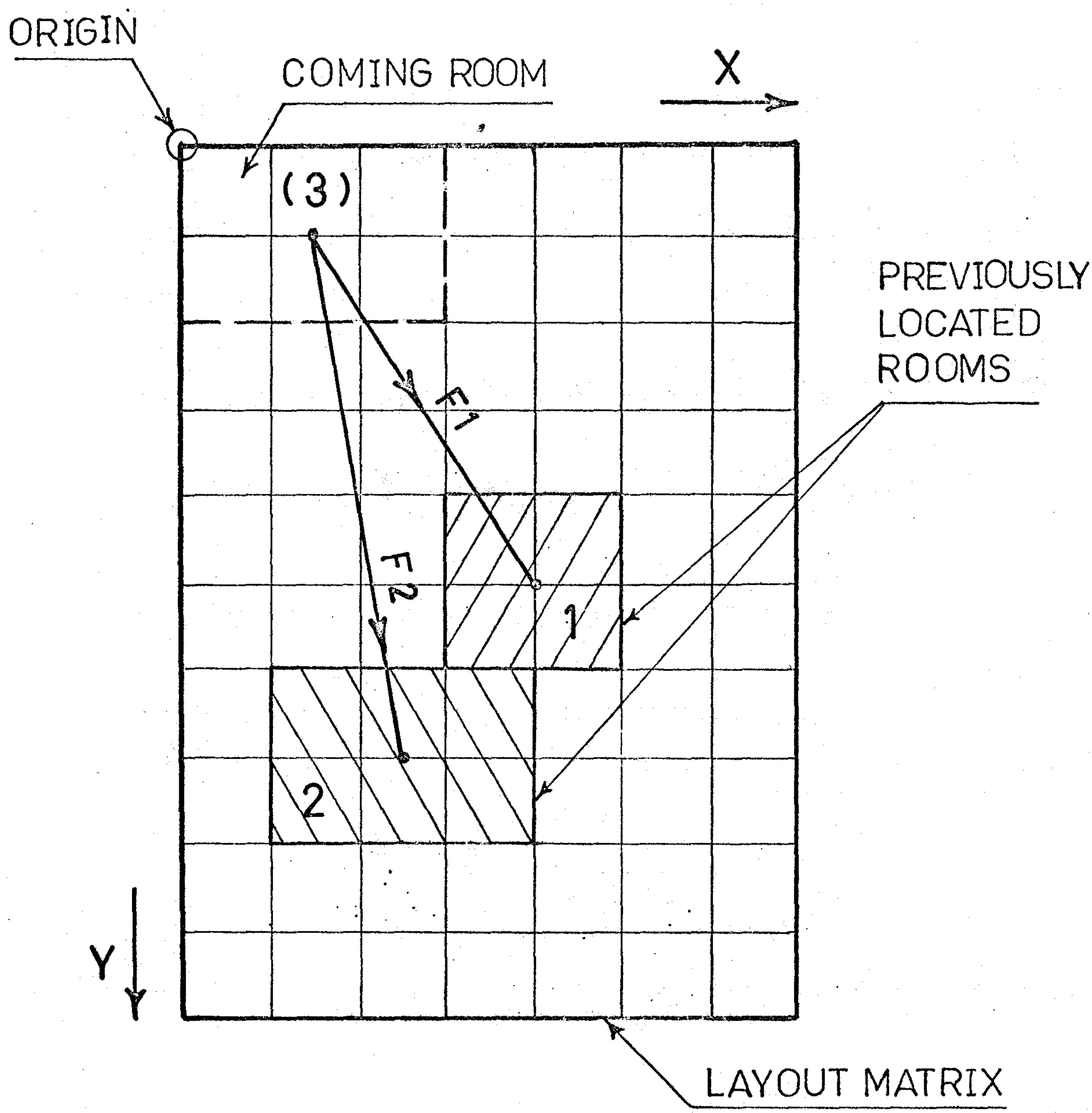


Figure 28:

THE LOCATION PROCESS MECHANISM

iii <u>The exposure directions:</u>

Sometimes the user will wish to specify certain exposure directions for certain rooms. For example, he might like the entrance or the garage to be exposed on the main street, or the bedrooms to look over the back garden. When planning a factory, the user might like the shipping and receiving departments to be placed on the plant perimeter in a certain direction.

The user can specify any exposure direction he wants for any room as input data with a maximum of two directions for each room, taking into consideration the position of his land relative to the surroundings and knowing that the produced plan layout will always have

- the top as direction number 1
- the right-hand side as direction number 2
- the bottom as direction number 3
- the left-hand side as direction number 4

To illustrate the logic of this part of a program, suppose that the third room to be located has an exposure direction number 2 and it was placed in its final position beside room number 1 and room number 2 (see Figure 29) with the exposure direction 2 free. Then all the units lying on the right-hand side of room number 3 are filled up with dummy parameters to insure that no other room will be placed in this space and violate the exposure direction specification previously satisfied. These dummy parameters are removed before printing an intermediate plan or a final plan.

The next phase is to use subroutine LOCATE to solve the problem of the location of the rooms.

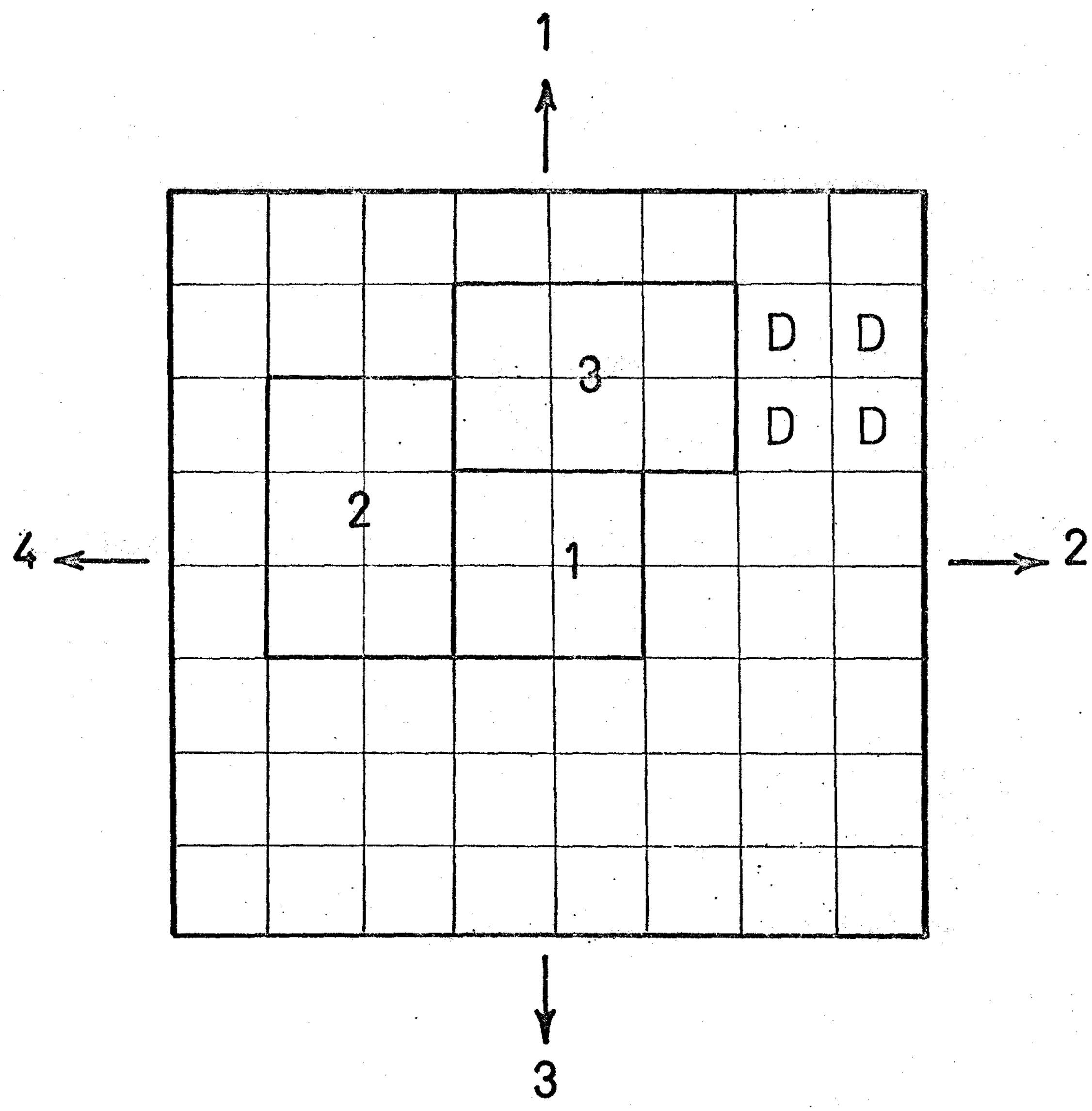


Figure 29:

HOW TO SATISFY THE EXPOSURE DIRECTIONS SPECIFICATIONS

A. Locating the first WINNER

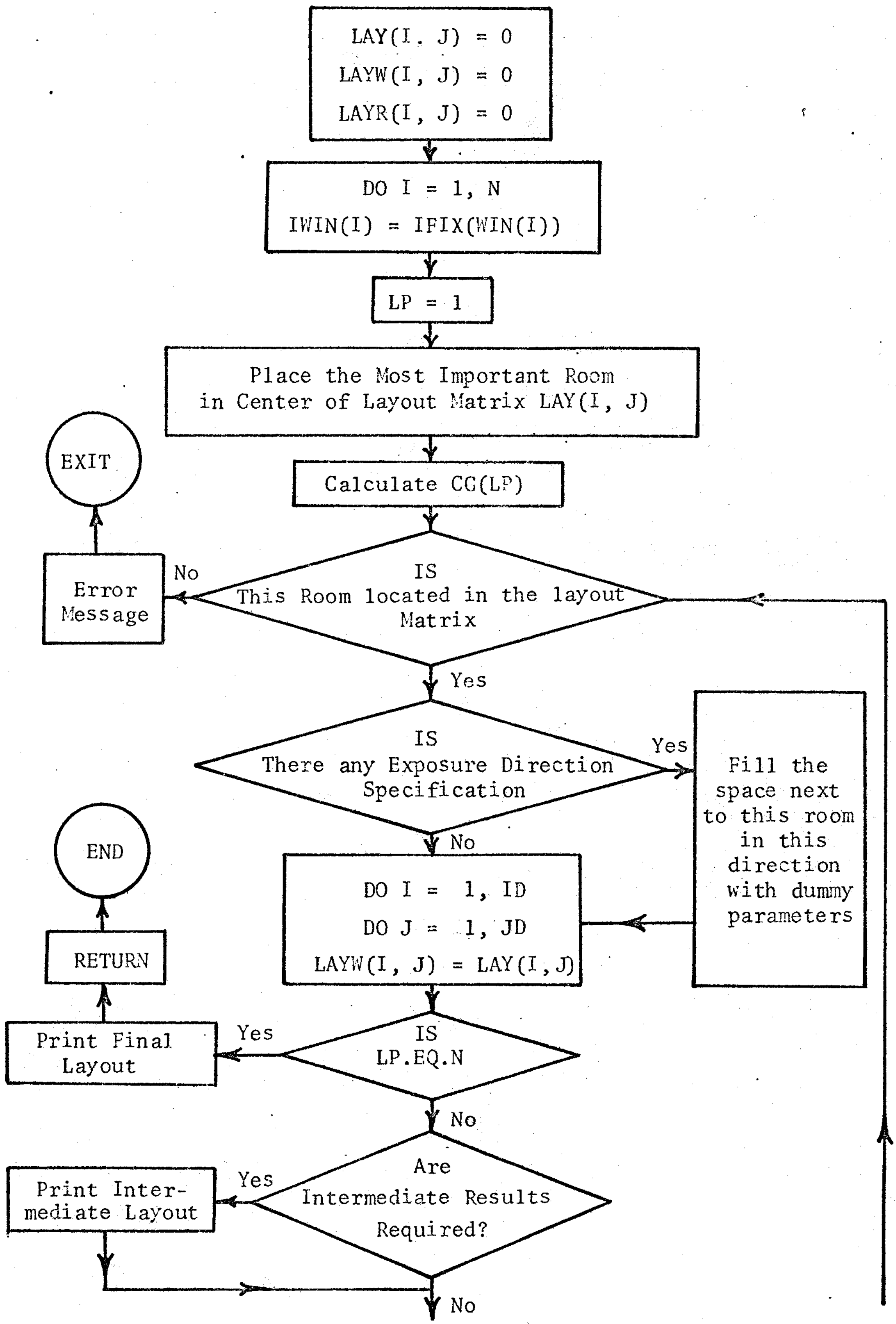
The first WINNER is located in the center of the layout matrix. the physical placement of the first WINNER is open to question, but it is strongly felt that this initial room or department should be placed in the center of the layout to allow completely unrestricted growth. This could cause difficulty if the first WINNER is the entrance hall, the shipping or receiving department, or any other room that should obviously be placed on the plan perimeter, or if the first WINNER became an interior room in the final plan layout. However, the user can always specify an appropriate exposure direction for the critical rooms or departments to avoid any undesirable position. (See the next chapter for more examples on house design and the adjustments needed for the block plan layout.)

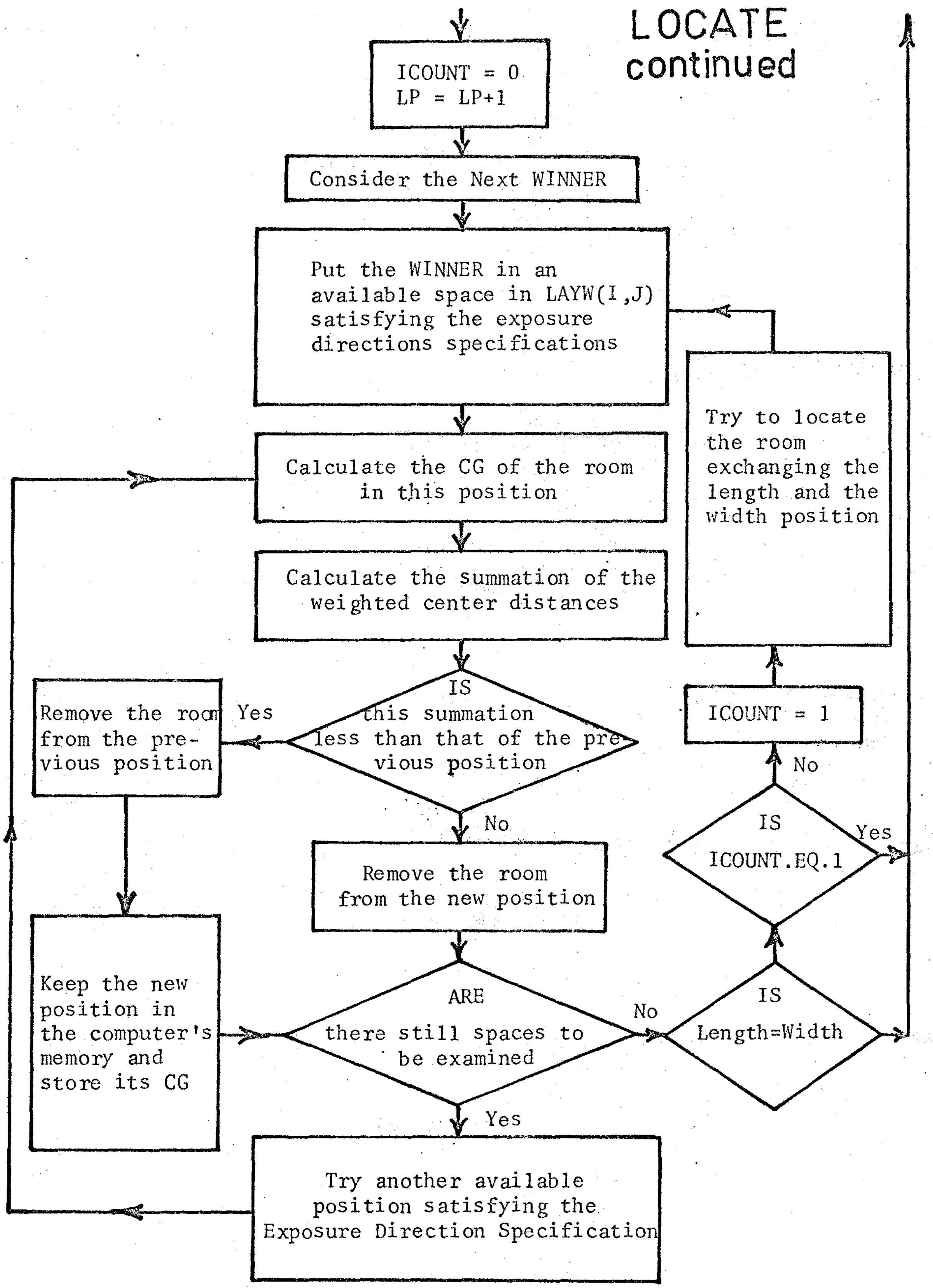
B. Locating the rest of the WINNERS

The subroutine continues placing the WINNERS one by one in the layout matrix, minimizing the sum of the weighted center distances as explained previously. Two very important checks are made prior to the placement of any room in any space. First, the space must be empty and second the specified exposure directions must be free. The intermediate plan layout is printed in matrix format, if desired, after placing each room. Another check is done to see if all rooms have been placed in the layout. If not, the subroutine places the next WINNER. When all rooms are presented in the layout, the final plan layout is printed, both in matrix format and as a plot on the graph plotter, which draws to scale the outlines of the final plan layout indicating the name of each room. The graph plotting has many advantages. The first, and most important one, is that it communicates results to the user in a readily usable form. Secondly, it is more visual than any other output in a matrix format. Thirdly, no effort is needed to draw the outlines of each room or to translate the rooms' numbers to their original names. A modular grid is provided from the graph plotter so that the user can try to adjust his plan layout on it.

Chart 6 explains the main processes taking place in Subroutine LOCATE.

chart 6:
Subroutine LOCATE




LOCATE
continued
ICOUNT = 0
LP = LP+1
Consider the Next WINNER
Put the WINNER in an available space in LAYW(I,J) satisfying the exposure directions specifications
Calculate the CG of the room in this position
Calculate the summation of the weighted center distances
IS this summation less than that of the previous position
Yes
No
Remove the room from the previous position
Keep the new position in the computer's memory and store its CG
Remove the room from the new position
ARE there still spaces to be examined
Yes
No
Try another available position satisfying the Exposure Direction Specification
IS Length=Width
IS ICOUNT.EQ.1
Yes
No
ICOUNT = 1
Try to locate the room exchanging the length and the width position

CHAPTER VI

TESTING THE PROGRAM

6.1 INTRODUCTION:

The purpose of this chapter is to present the use of the developed computer program coupled with the new proposed housebuilding system in designing houses and other types of buildings. The first and second example show the design of two different houses, the third example shows design of a nursery school. Some very simple cases are tried at the beginning to show how the program works.

The way of preparing the input data, the user's main program, and the Relationship Chart are presented and the transformation of the produced block layout to an architectural floor plan is explained with some details showing the flexibility of the proposed housebuilding system.

One of the most attractive features of the technique used in this program is that it enables the user to specify varying room and department sizes or shapes; also each space can have up to two free exposure directions. These features greatly ease the transformation processes. The program has many parameters which are user-controlled to allow for the maximum possible amount of flexibility. The user can specify varied output information, a check of the input data, along with a combination of error and location failure messages.

The architect and client must know, prior to the application of the technique, that the results obtained will be truly representative of their design problem and that the final schematic solution will only be as good as the input data. Also, the architect must realize that computers can save him much time and can improve the results of his work.

It is important to note that interior corridors, passage ways, and halls are not to be considered as individual rooms or departments to avoid any preconception of a plan which disregards rational design approach based on quantifiable criteria. The necessary adjustments for corridor space is made when the diagramatic solution is transferred into a real layout.

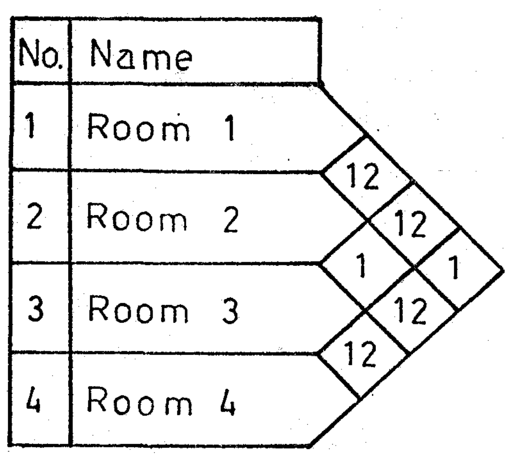
6.2 PLAN TRANSFORMATION:

The final task of this procedure is to transform the schematic floor plan into a real working floor plan. After the schematic solution is developed by the program, it is necessary to determine what considerations and knowledge are required in order to obtain a final architectural floor plan which exploits the work done by the program. For the architectural problem of space allocation to provide the best functional building layout, the entire range of considerations that must be evaluated is much more encompassing than the closeness ratings, relationships or circulation cost. It is the architect's job to transform the schematic solution to an architectural termination, incorporating all the human, aesthetic, and other considerations into the layout.

It should be remembered that the distance calculations for the location process evaluation were measured from center of space to center of space, and, thus, when the final architectural layout is developed, care should be taken to maintain, or if possible to improve, the distance relationships between functions.

6.3 TEST CASES:

The object of these test cases is to show how the program deals with the exposure direction specifications along with the specified relationships between the different rooms. Suppose that we have a unit which consists of four rooms having the following configuration and Relationship Chart, the final plan layout provided illustrate how the layout changes according to the change in the exposure directions of the different rooms without changing their sizes or the relationships between them.



OPTIMUM PLAN LAYOUT USING THE NEGHBOURING TECHNIQUE
****

NUMBER OF ROOMS TO BE LOCATED.................N	=	4		
LAND LENGTH......................................XL	=	40.000	FEET	
LAND WIDTH.......................................YL	=	40.000	FEET	

INITIAL SPATIAL CONFIGURATION OF EACH ROOM

NO.	NAME	LENGTH(FEET)	WIDTH(FEET)	AREA	EXPOSURE	DIRECTION
1	ROOM 1	0.00	0.00	100.00	0	0
2	ROOM 2	0.00	0.00	100.00	0	0
3	ROOM 3	0.00	0.00	100.00	0	0
4	ROOM 4	0.00	0.00	100.00	0	0

THE RELATIONSHIP CHART

	1	2	3	4
1				
2	12			
3	12	1		
4	1	12	12	

Computer Output : 1

REFERENCE FILES

****

ORDERED SEQUENCE OF ROOMS ACCORDING TO DECREASING TCR

ROOM NO.	AREA	LENGTH	WIDTH	TCR
1	9	3	3	25
2	9	3	3	25
3	9	3	3	25
4	9	3	3	25

**NOTE BOTH LENGTH AND WIDTH ARE REPRESENTED IN MODULES
ONE MODULE = 40 INCHES

SIZE OF THE LAYOUT MATRIX

NUMBER OF ROWS = 11

NUMBER OF COLUMNS= 11

SEQUENCE OF WINNERS

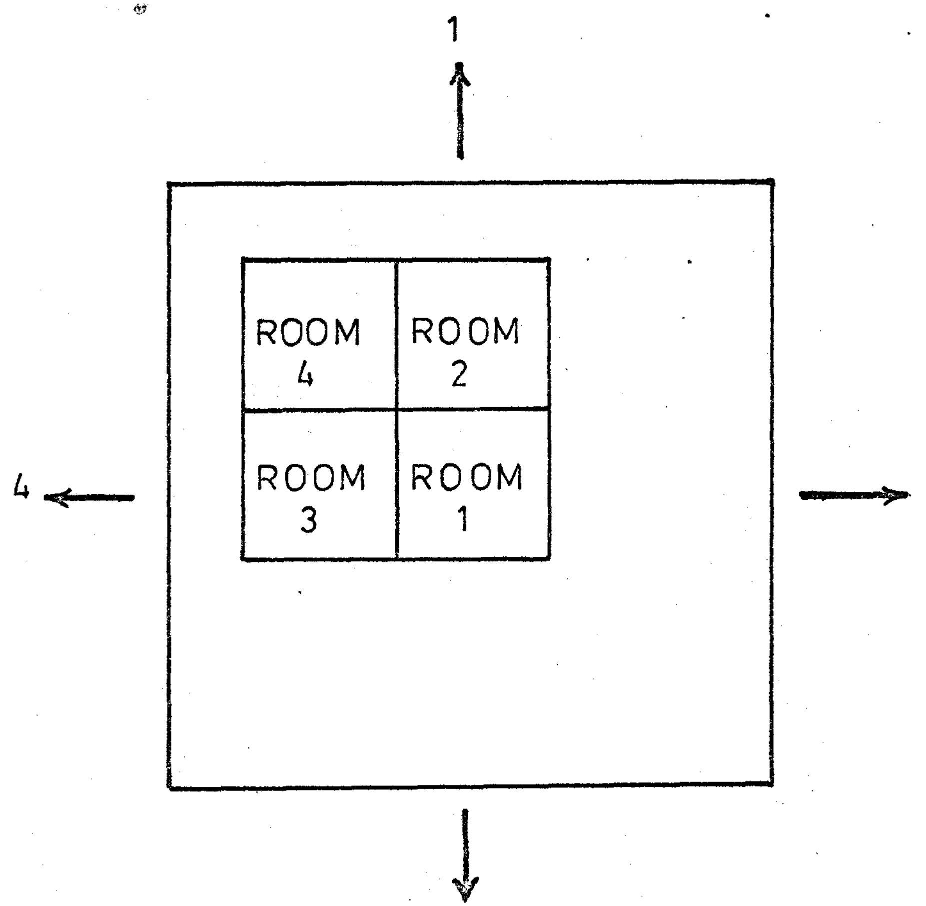
NO.	ROOM NO.
1	1
2	2
3	3
4	4

Computer Output : 2

CASE 1: No Direction Specification

FINAL PLAN LAYOUT

0	0	0	0	0	0	0	0	0	0	0
0	4	4	4	2	2	2	0	0	0	0
0	4	4	4	2	2	2	0	0	0	0
0	4	4	4	2	2	2	0	0	0	0
0	3	3	3	1	1	1	0	0	0	0
0	3	3	3	1	1	1	0	0	0	0
0	3	3	3	1	1	1	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0



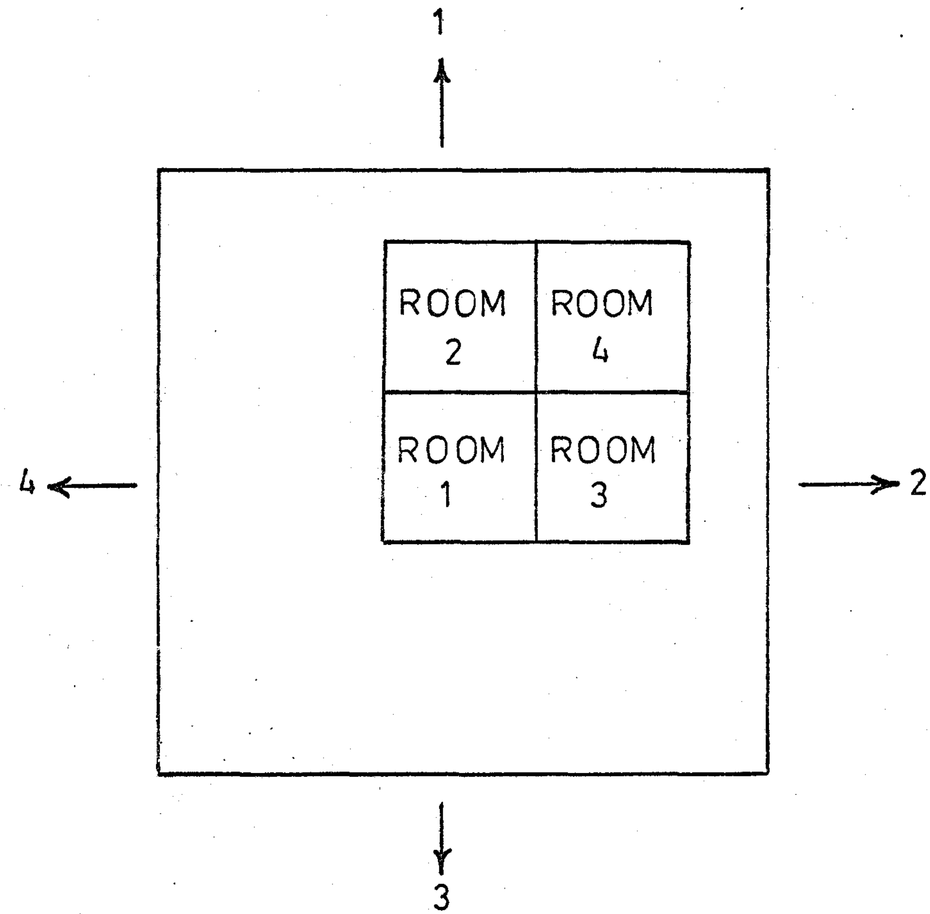
* THE SCORE OF THIS LAYOUT IS = 76.2426
* NOTE THE LESS THE SCORE THE BETTER THE LAYOUT

Computer Output: 3

CASE 2: IDRC1(3)=2

FINAL PLAN LAYOUT

0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	2	2	2	4	4	4	0
0	0	0	0	2	2	2	4	4	4	0
0	0	0	0	2	2	2	4	4	4	0
0	0	0	0	1	1	1	3	3	3	0
0	0	0	0	1	1	1	3	3	3	0
0	0	0	0	1	1	1	3	3	3	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0



* THE SCORE OF THIS LAYOUT IS =   76.2426

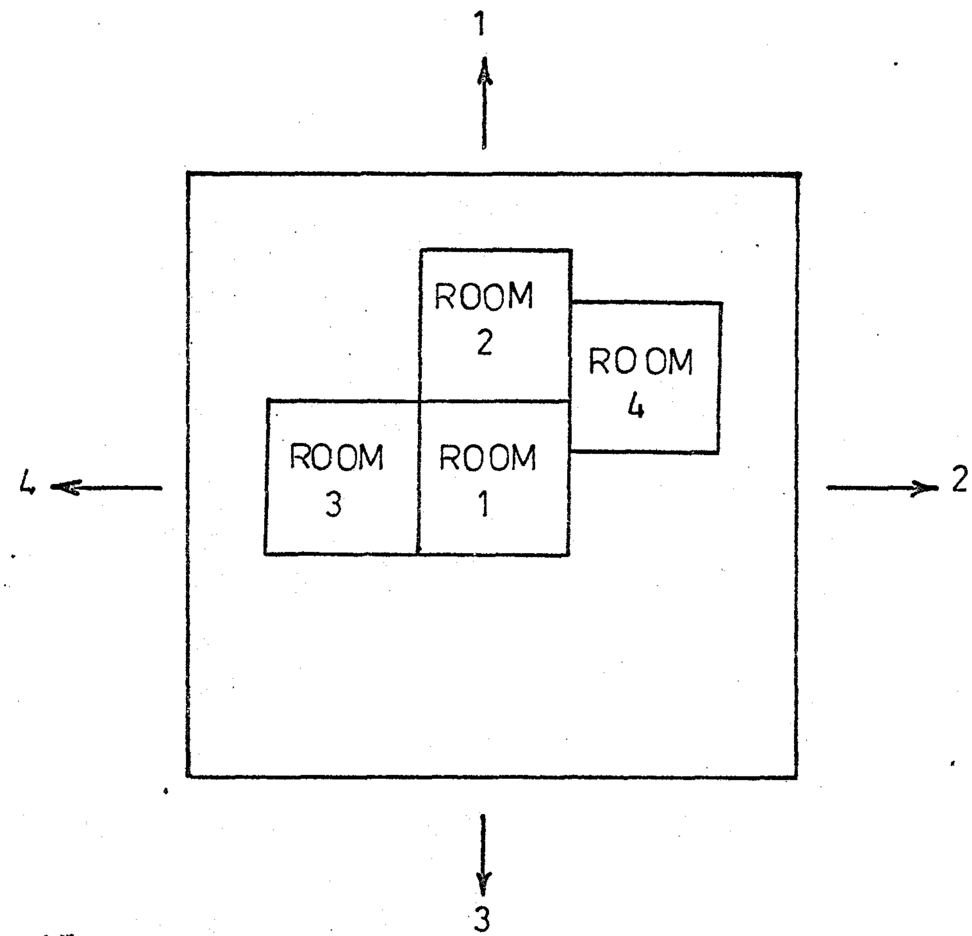
* NOTE THE LESS THE SCORE THE BETTER THE LAYOUT

Computer Output : 4

CASE 3: IDRC1(4)=3

FINAL PLAN LAYOUT

0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	2	2	2	0	0	0	0
0	0	0	0	2	2	2	4	4	4	0
0	0	0	0	2	2	2	4	4	4	0
0	3	3	3	1	1	1	4	4	4	0
0	3	3	3	1	1	1	0	0	0	0
0	3	3	3	1	1	1	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0



* THE SCORE OF THIS LAYOUT IS = 117.4475

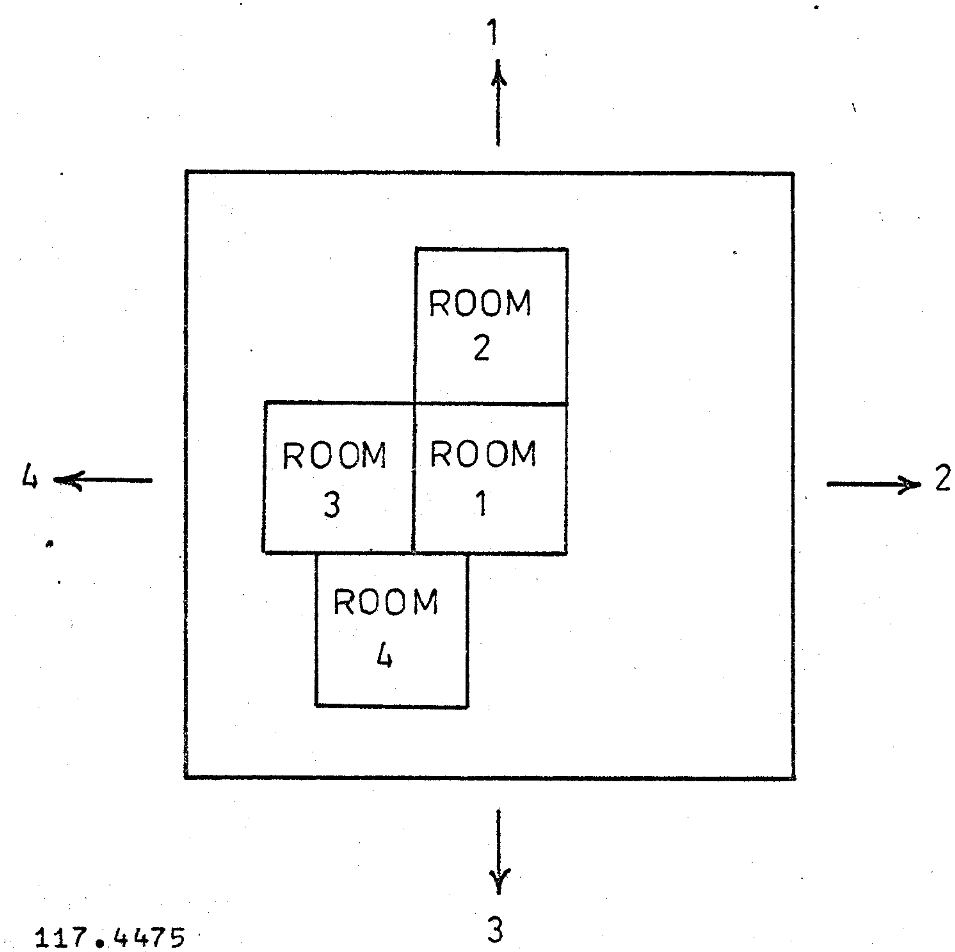
* NOTE THE LESS THE SCORE THE BETTER THE LAYOUT

Computer Output: 5

CASE 4: IDRC1(2)=2& IDRC2(2)=4

FINAL PLAN LAYOUT

0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	2	2	2	0	0	0	0
0	0	0	0	2	2	2	0	0	0	0
0	0	0	0	2	2	2	0	0	0	0
0	3	3	3	1	1	1	0	0	0	0
0	3	3	3	1	1	1	0	0	0	0
0	3	3	3	1	1	1	0	0	0	0
0	0	4	4	4	0	0	0	0	0	0
0	0	4	4	4	0	0	0	0	0	0
0	0	4	4	4	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0



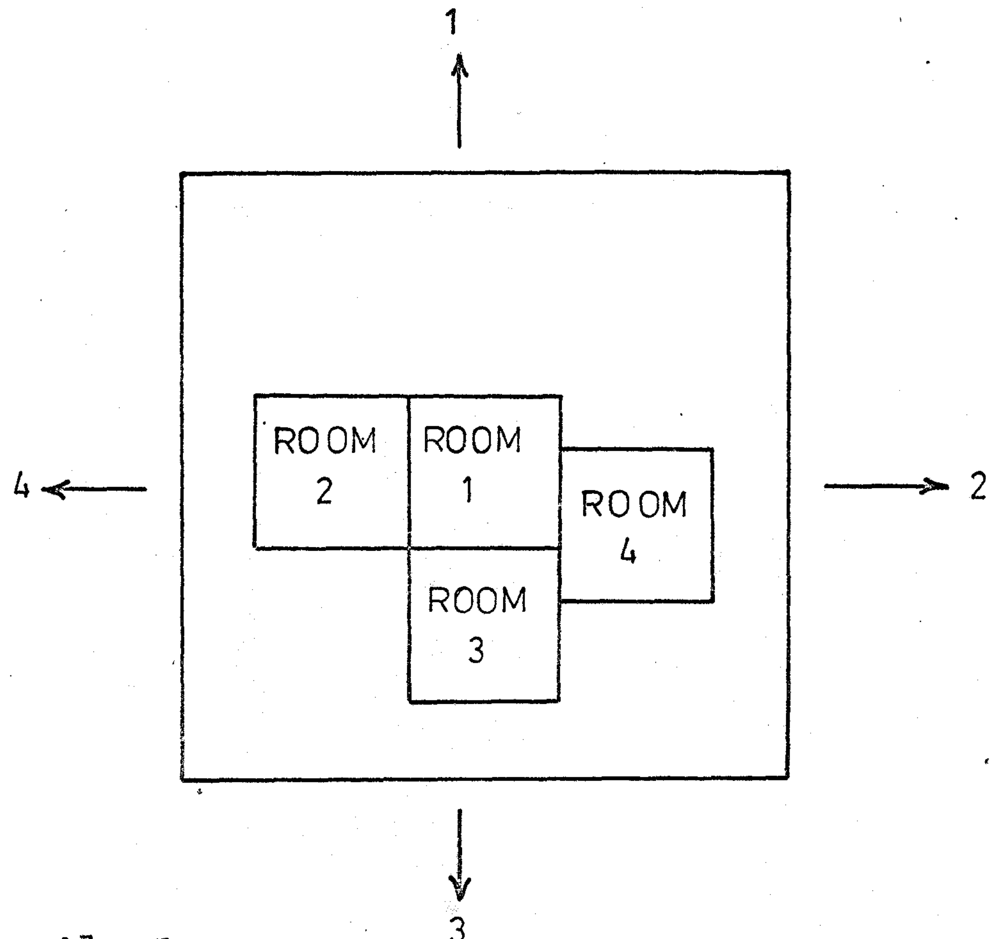
* THE SCORE OF THIS LAYOUT IS = 117.4475
* NOTE THE LESS THE SCORE THE BETTER THE LAYOUT

Computer Output: 6

CASE 5 : IDRC1(1)=1 , IDRC1(2)=1 , IDRC2(2)=3

FINAL PLAN LAYOUT

0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	2	2	2	1	1	1	0	0	0	0
0	2	2	2	1	1	1	0	0	0	0
0	2	2	2	1	1	1	4	4	4	0
0	0	0	0	3	3	3	4	4	4	0
0	0	0	0	3	3	3	4	4	4	0
0	0	0	0	3	3	3	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0



* THE SCORE OF THIS LAYOUT IS = 117.4475

* NOTE THE LESS THE SCORE THE BETTER THE LAYOUT

Computer Output: 7

6.4 TWO-BEDROOMS HOUSE DESIGN

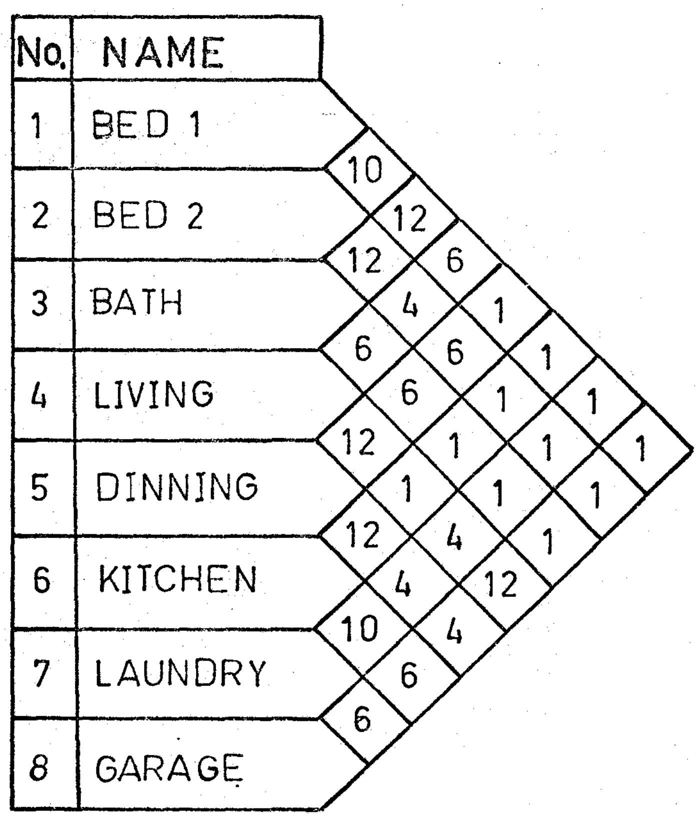


Figure: 30

Relationship Chart

THE CALLING PROGRAM

```
      PROGRAM TST (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE10)
      DIMENSION XNAME(8),X(8),Y(8),A(8),WAIT(28),CLOSE(8,8),MX(8),MY(8),
     $MXY(8),PRIOR(8),WIN(8),TOTAL(8),IDRC1(8),IDRC2(8),IWIN(8),TCR(8),
     $CG(8),CGF(8),CD(8),TCR1(8)
      COMPLEX CG, CGF
C
      N = 8
      NN = 28
      IDATA=1
      INTRMD=1
      IREF=1
      XL = 0.0
      YL = 0.0
      DATA UNAME/6HHODA H/
      DATA XNAME/5HBED 1,5HBED 2,4HBATH,6HLIVING,7HDINNING,7HKITCHEN,7HL
     $AUNDRY,6HGARAGE/
      DATA X/10.,10.,0.,0.,0.,8.,8.,14./
      DATA Y/10.,10.,0.,0.,0.,8.,8.,10./
      DATA A/100.,120.,45.,180.,160.,64.,64.,140./
      DATA IDRC1/0,0,0,0,0,0,0,0/
      DATA IDRC2/0,0,0,0,0,0,0,0/
      DATA WAIT/10.,12.,6.,1.,1.,1.,1.,12.,4.,6.,1.,1.,1.,6.,6.,1.,1.,1.
     $,12.,1.,4.,12.,12.,4.,4.,10.,6.,6./
C
      CALL OCREPL(N,NN,IDATA,INTRMD,IREF,XNAME,X,Y,A,WAIT,CLOSE,MX,MY,
     $MXY,TCR,PRIOR,WIN,IWIN,TOTAL,CG,CGF,CD,TCR1,IDRC1,IDRC2,XL,YL,UNAM
     $E)
C
      STOP
      END
```

Computer Output : 8

OPTIMUM PLAN LAYOUT USING THE NEGHBOURING TECHNIQUE
****

NUMBER OF ROOMS TO BE LOCATED..................N = 8
LAND LENGTH....................................XL = 0.000 FEET

LAND WIDTH.....................................YL = 0.000 FEET

INITIAL SPATIAL CONFIGURATION OF EACH ROOM

NO.	NAME	LENGTH(FEET)	WIDTH(FEET)	AREA	EXPOSURE	DIRECTION
1	BED 1	10.00	10.00	100.00	0	0
2	BED 2	10.00	10.00	120.00	0	0
3	BATH	0.00	0.00	45.00	0	0
4	LIVING	0.00	0.00	180.00	0	0
5	DINNING	0.00	0.00	160.00	0	0
6	KITCHEN	8.00	8.00	64.00	0	0
7	LAUNDRY	8.00	8.00	64.00	0	0
8	GARAGE	14.00	10.00	140.00	0	0

THE RELATIONSHIP CHART

	1	2	3	4	5	6.	7	8
1								
2	10							
3	12	12						
4	6	4	6					
5	1	6	6	12				
6	1	1	1	1	12			
7	1	1	1	4	4	10		
8	1	1	1	12	4	6	6	

Computer Output : 9

REFERENCE FILES

****

ORDERED SEQUENCE OF ROOMS ACCORDING TO DECREASING TCR

ROOM NO.	AREA	LENGTH	WIDTH	TCR
4	16	4	4	45
5	16	4	4	45
3	4	2	2	39
2	9	3	3	35
1	9	3	3	32
6	6	3	2	32
8	15	5	3	31
7	6	3	2	27

**NOTE BOTH LENGTH AND WIDTH ARE REPRESENTED IN MODULES
ONE MODULE = 40 INCHES

SIZE OF THE LAYOUT MATRIX

NUMBER OF ROWS = 16

NUMBER OF COLUMNS= 16

SEQUENCE OF WINNERS

NO.	ROOM NO.
1	4
2	5
3	8
4	6
5	7
6	3
7	2
8	1

Computer Output : 10

INTERMEDIATE PLAN LAYOUT   STAGE NO.   1

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	4	4	4	4	0	0	0	0	0	0
0	0	0	0	0	0	4	4	4	4	0	0	0	0	0	0
0	0	0	0	0	0	4	4	4	4	0	0	0	0	0	0
0	0	0	0	0	0	4	4	4	4	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Computer Output: 11

INTERMEDIATE PLAN LAYOUT STAGE NO. 2

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	5	5	5	5	0	0	0	0	0	0
0	0	0	0	0	0	5	5	5	5	0	0	0	0	0	0
0	0	0	0	0	0	5	5	5	5	0	0	0	0	0	0
0	0	0	0	0	0	5	5	5	5	0	0	0	0	0	0
0	0	0	0	0	0	4	4	4	4	0	0	0	0	0	0
0	0	0	0	0	0	4	4	4	4	0	0	0	0	0	0
0	0	0	0	0	0	4	4	4	4	0	0	0	0	0	0
0	0	0	0	0	0	4	4	4	4	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Continued

INTERMEDIATE PLAN LAYOUT STAGE NO. 3

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	5	5	5	5	0	0	0	0	0	0
0	0	0	0	0	0	5	5	5	5	0	0	0	0	0	0
0	0	0	0	0	0	5	5	5	5	0	0	0	0	0	0
0	0	0	8	8	8	5	5	5	5	0	0	0	0	0	0
0	0	0	8	8	8	4	4	4	4	0	0	0	0	0	0
0	0	0	8	8	8	4	4	4	4	0	0	0	0	0	0
0	0	0	8	8	8	4	4	4	4	0	0	0	0	0	0
0	0	0	8	8	8	4	4	4	4	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Continued

INTERMEDIATE PLAN LAYOUT STAGE NO. 4

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	6	6	5	5	5	5	0	0	0	0	0	0
0	0	0	0	6	6	5	5	5	5	0	0	0	0	0	0
0	0	0	0	6	6	5	5	5	5	0	0	0	0	0	0
0	0	0	8	8	8	5	5	5	5	0	0	0	0	0	0
0	0	0	8	8	8	4	4	4	4	0	0	0	0	0	0
0	0	0	8	8	8	4	4	4	4	0	0	0	0	0	0
0	0	0	8	8	8	4	4	4	4	0	0	0	0	0	0
0	0	0	8	8	8	4	4	4	4	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Continued

INTERMEDIATE PLAN LAYOUT   STAGE NO.   5

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	7	7	6	6	5	5	5	5	0	0	0	0	0	0
0	0	7	7	6	6	5	5	5	5	0	0	0	0	0	0
0	0	7	7	6	6	5	5	5	5	0	0	0	0	0	0
0	0	0	8	8	8	5	5	5	5	0	0	0	0	0	0
0	0	0	8	8	8	4	4	4	4	0	0	0	0	0	0
0	0	0	8	8	8	4	4	4	4	0	0	0	0	0	0
0	0	0	8	8	8	4	4	4	4	0	0	0	0	0	0
0	0	0	8	8	8	4	4	4	4	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Continued

INTERMEDIATE PLAN LAYOUT STAGE NO. 6

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	7	7	6	6	5	5	5	5	0	0	0	0	0	0
0	0	7	7	6	6	5	5	5	5	0	0	0	0	0	0
0	0	7	7	6	6	5	5	5	5	0	0	0	0	0	0
0	0	0	8	8	8	5	5	5	5	3	3	0	0	0	0
0	0	0	8	8	8	4	4	4	4	3	3	0	0	0	0
0	0	0	8	8	8	4	4	4	4	0	0	0	0	0	0
0	0	0	8	8	8	4	4	4	4	0	0	0	0	0	0
0	0	0	8	8	8	4	4	4	4	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Continued

INTERMEDIATE PLAN LAYOUT STAGE NO. 7

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	7	7	6	6	5	5	5	5	2	2	2	0	0	0
0	0	7	7	6	6	5	5	5	5	2	2	2	0	0	0
0	0	7	7	6	6	5	5	5	5	2	2	2	0	0	0
0	0	0	8	8	8	5	5	5	5	3	3	0	0	0	0
0	0	0	8	8	8	4	4	4	4	3	3	0	0	0	0
0	0	0	8	8	8	4	4	4	4	0	0	0	0	0	0
0	0	0	8	8	8	4	4	4	4	0	0	0	0	0	0
0	0	0	8	8	8	4	4	4	4	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Continued

FINAL PLAN LAYOUT

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	7	7	6	6	5	5	5	5	2	2	2	0	0	0
0	0	7	7	6	6	5	5	5	5	2	2	2	0	0	0
0	0	7	7	6	6	5	5	5	5	2	2	2	0	0	0
0	0	0	8	8	8	5	5	5	5	3	3	0	0	0	0
0	0	0	8	8	8	4	4	4	4	3	3	0	0	0	0
0	0	0	8	8	8	4	4	4	4	1	1	1	0	0	0
0	0	0	8	8	8	4	4	4	4	1	1	1	0	0	0
0	0	0	8	8	8	4	4	4	4	1	1	1	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

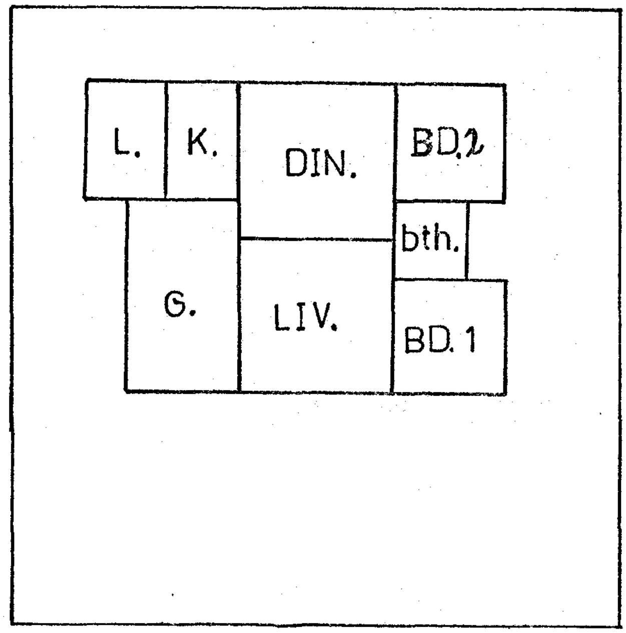
* THE SCORE OF THIS LAYOUT IS = 132.6414
* NOTE THE LESS THE SCORE THE BETTER THE LAYOUT

Computer Output:12

PLAN LAYOUT

i- Computer Output

Computer Time = 7.68 seconds



ii- Adjusted

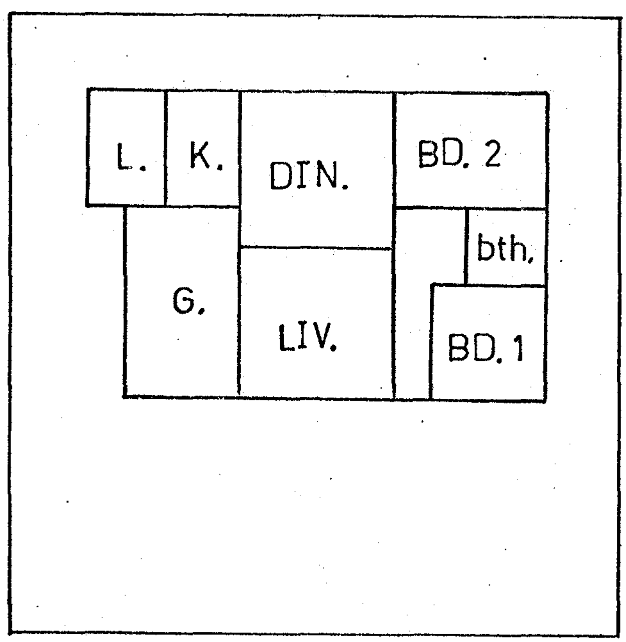


Figure: 31

ARCHITECTURAL PLAN LAYOUT

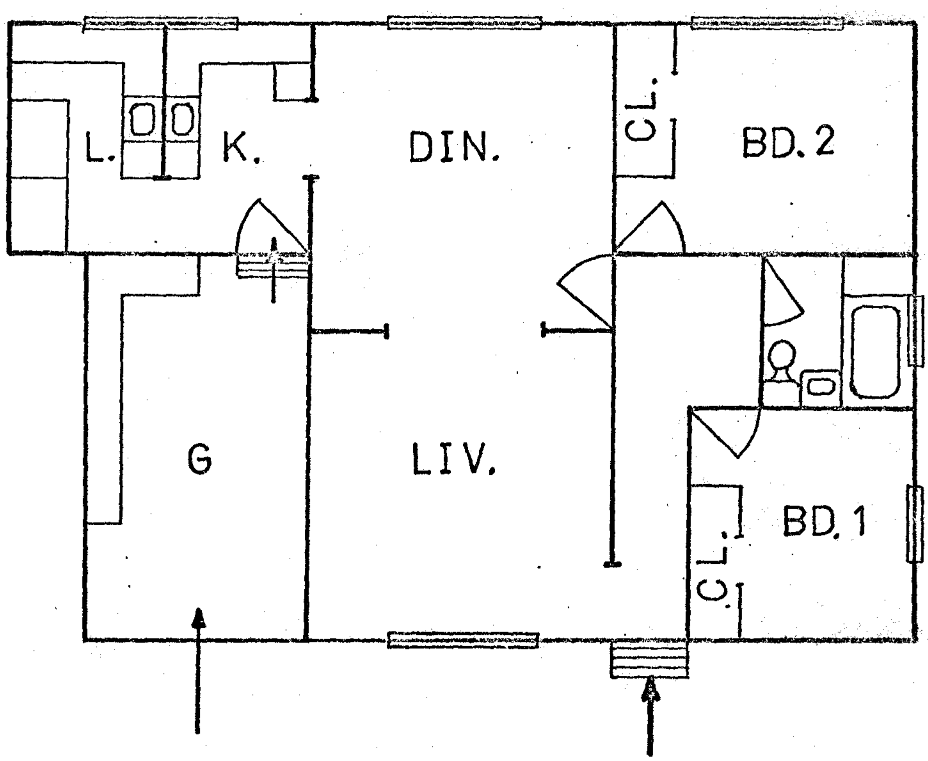


Figure: 32

6.5 THREE – BEDROOMS HOUSE DESIGN

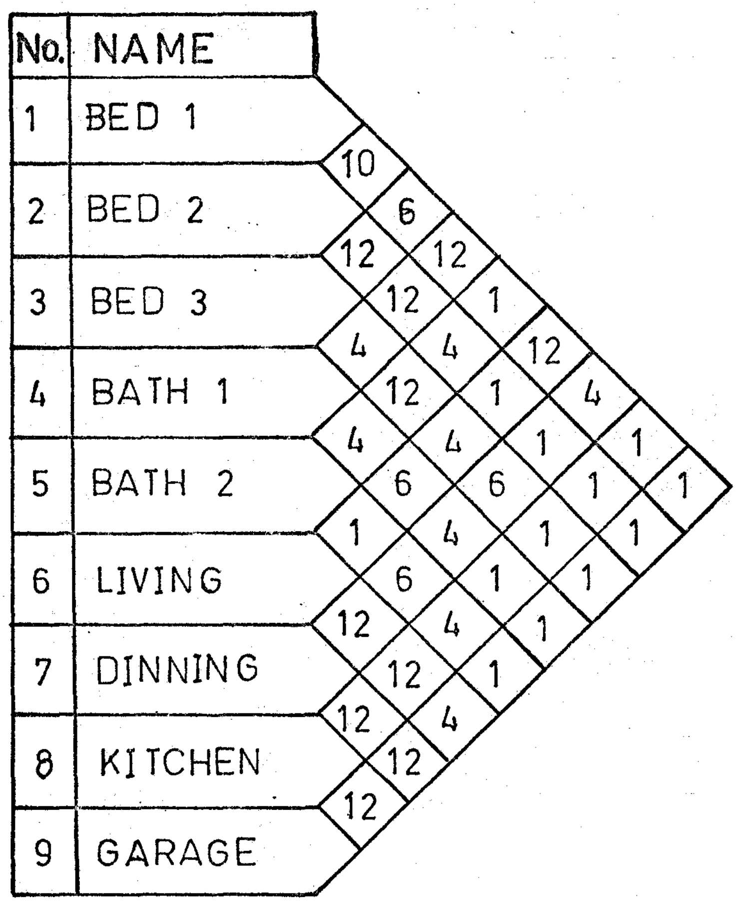


Figure: 33

Relationship Chart

OPTIMUM PLAN LAYOUT USING THE NEGHBOURING TECHNIQUE

****

NUMBER OF ROOMS TO BE LOCATED....................N = 9

LAND LENGTH......................................XL = 0.000 FEET

LAND WIDTH.......................................YL = 0.000 FEET

INITIAL SPATIAL CONFIGURATION OF EACH ROOM

NO.	NAME	LENGTH(FEET)	WIDTH(FEET)	AREA	EXPOSURE	DIRECTION
1	BED 1	10.00	10.00	100.00	0	0
2	BED 2	10.00	10.00	100.00	0	0
3	BED 3	10.00	10.00	100.00	0	0
4	BATH 1	0.00	10.00	65.00	0	0
5	BATH 2	0.00	10.00	65.00	0	0
6	LIVING	20.00	10.00	200.00	0	0
7	DINNING	10.00	10.00	100.00	0	0
8	KITCHEN	10.00	10.00	100.00	0	0
9	GARAGE	17.00	10.00	170.00	0	0

THE RELATIONSHIP CHART

	1	2	3	4	5	6	7	8	9
1									
2	10								
3	6	12							
4	12	12	4						
5	1	4	12	4					
6	12	1	4	6	1				
7	4	1	6	4	6	12			
8	1	1	1	1	4	12	12		
9	1	1	1	1	1	4	12	12	

Computer Output : 13

REFERENCE FILES

****

ORDERED SEQUENCE OF ROOMS ACCORDING TO DECREASING TCR

ROOM NO.	AREA	LENGTH	WIDTH	TCR
7	9	3	3	57
6	18	6	3	52
1	9	3	3	47
3	9	3	3	46
4	6	2	3	44
8	9	3	3	44
2	9	3	3	42
5	6	2	3	33
9	18	6	3	33

**NOTE BOTH LENGTH AND WIDTH ARE REPRESENTED IN MODULES
ONE MODULE = 40 INCHES

SIZE OF THE LAYOUT MATRIX

NUMBER OF ROWS = 19

NUMBER OF COLUMNS= 19

SEQUENCE OF WINNERS

NO.	ROOM NO.
1	7
2	6
3	8
4	9
5	1
6	4
7	3
8	2
9	5

Computer Output : 14

FINAL PLAN LAYOUT

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	1	1	1	4	4	2	2	2	0	0	0	0
0	0	0	0	0	0	0	1	1	1	4	4	2	2	2	0	0	0	0
0	0	0	0	0	0	0	1	1	1	4	4	2	2	2	0	0	0	0
0	0	0	0	0	0	6	6	6	6	6	6	3	3	3	0	0	0	0
0	0	0	0	0	0	6	6	6	6	6	6	3	3	3	0	0	0	0
0	0	0	0	0	0	6	6	6	6	6	6	3	3	3	0	0	0	0
0	0	0	0	0	8	8	8	7	7	7	5	5	5	0	0	0	0	0
0	0	0	0	0	8	8	8	7	7	7	5	5	5	0	0	0	0	0
0	0	0	0	0	8	8	8	7	7	7	0	0	0	0	0	0	0	0
0	0	0	0	0	9	9	9	9	9	9	0	0	0	0	0	0	0	0
0	0	0	0	0	9	9	9	9	9	9	0	0	0	0	0	0	0	0
0	0	0	0	0	9	9	9	9	9	9	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

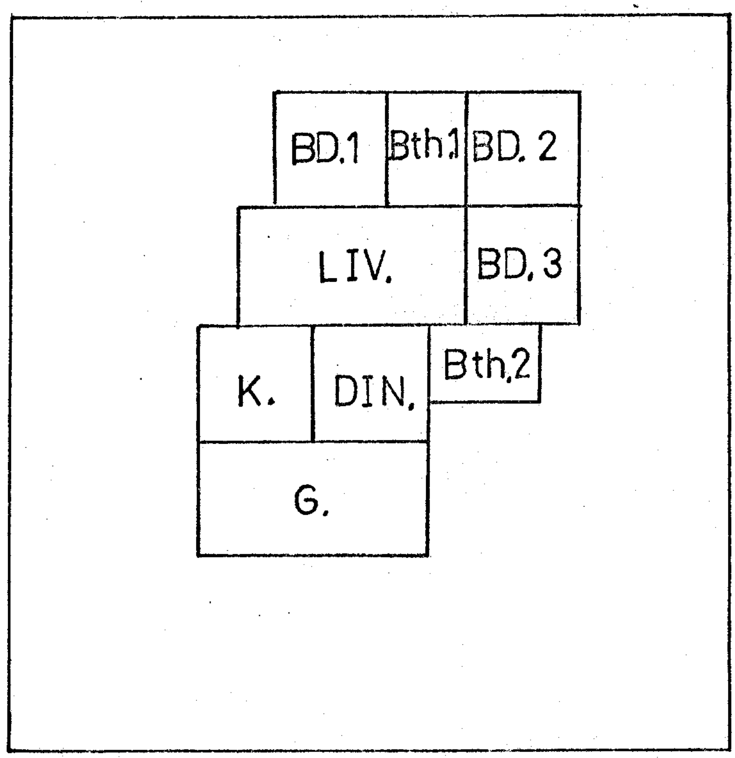
* THE SCORE OF THIS LAYOUT IS = 136.6094
* NOTE THE LESS THE SCORE THE BETTER THE LAYOUT

Computer Output: 15

PLAN LAYOUT

i- Computer Output

Computer Time = 11.28 seconds



ii- Adjusted

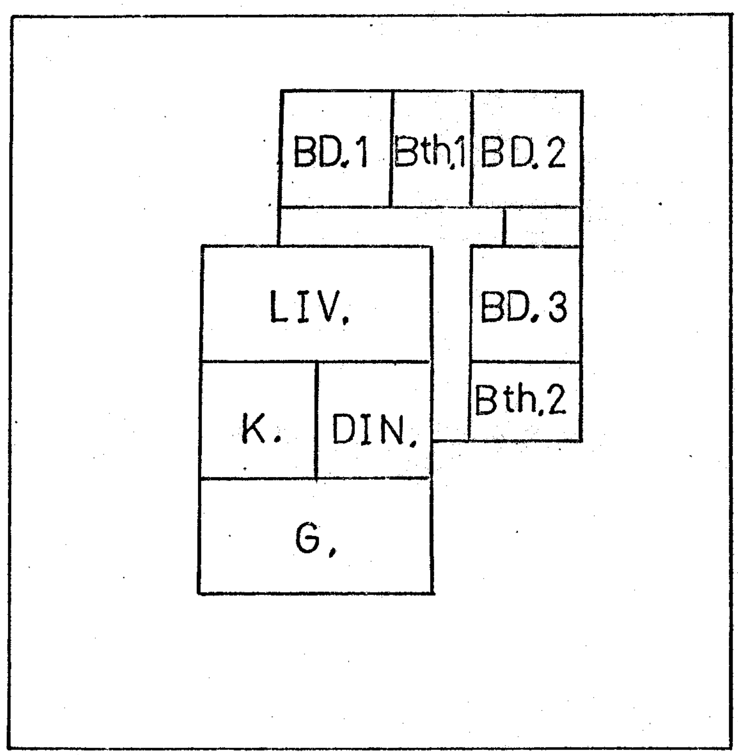


Figure : 34

IDRC1(6)=1

FINAL PLAN LAYOUT

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	6	6	6	6	6	6	0	0	0	0	0	0	0
0	0	0	0	0	0	6	6	6	6	6	6	4	4	4	0	0	0	0
0	0	0	0	0	0	6	6	6	6	6	6	4	4	4	0	0	0	0
0	0	0	0	0	8	8	8	7	7	7	1	1	1	2	2	2	0	0
0	0	0	0	0	8	8	8	7	7	7	1	1	1	2	2	2	0	0
0	0	0	0	0	8	8	8	7	7	7	1	1	1	2	2	2	0	0
0	0	0	0	0	9	9	9	9	9	9	3	3	3	5	5	0	0	0
0	0	0	0	0	9	9	9	9	9	9	3	3	3	5	5	0	0	0
0	0	0	0	0	9	9	9	9	9	9	3	3	3	5	5	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

* THE SCORE OF THIS LAYOUT IS = 158.0048

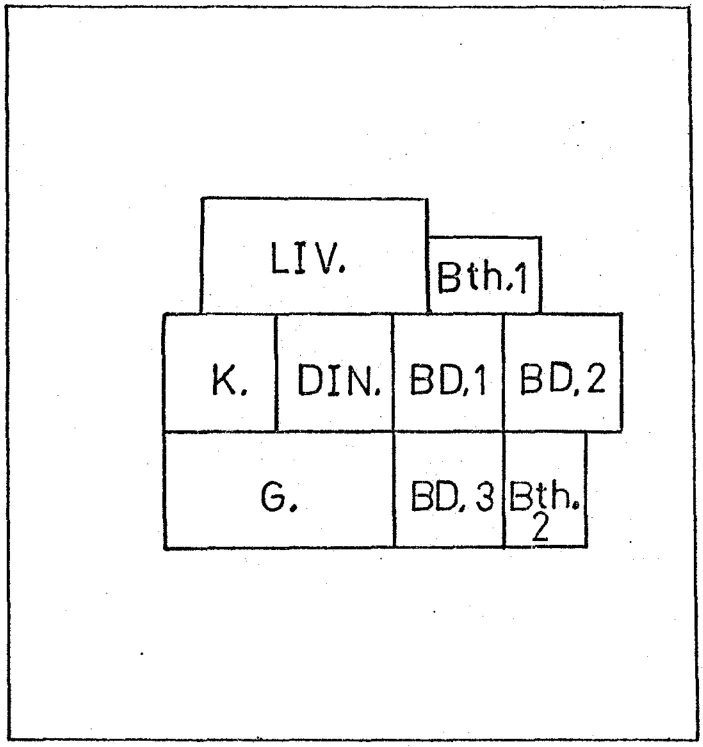
* NOTE THE LESS THE SCORE THE BETTER THE LAYOUT

Computer Output : 16

PLAN LAYOUT

i-Computer Output

Computer Time = 11.25 seconds



ii- Adjusted

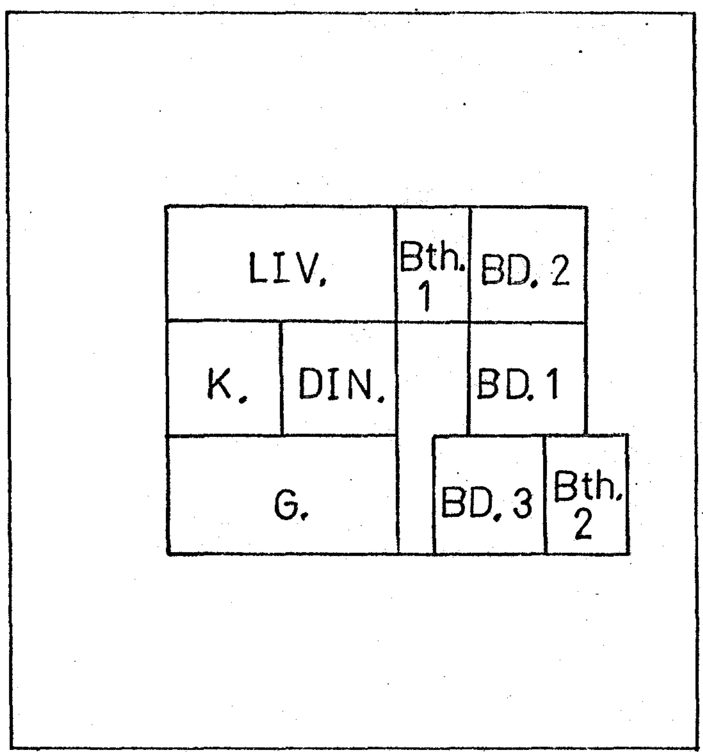


Figure: 35

ARCHITECTURAL PLAN LAYOUT

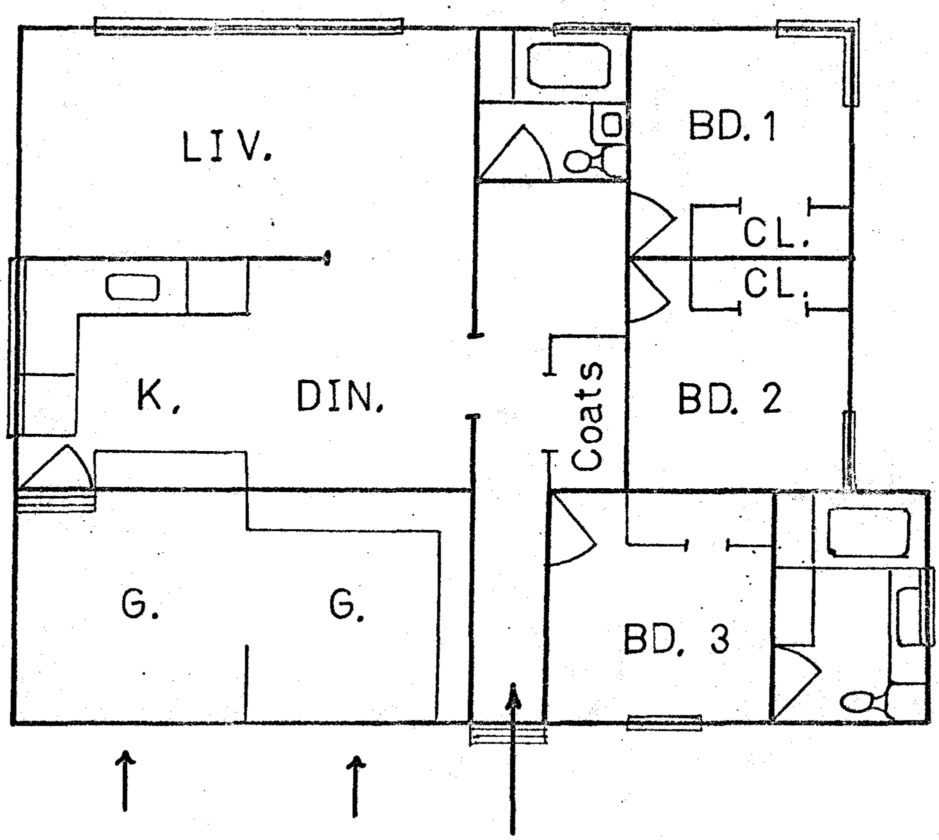


Figure : 36

6.6 A NURSERY SCHOOL DESIGN

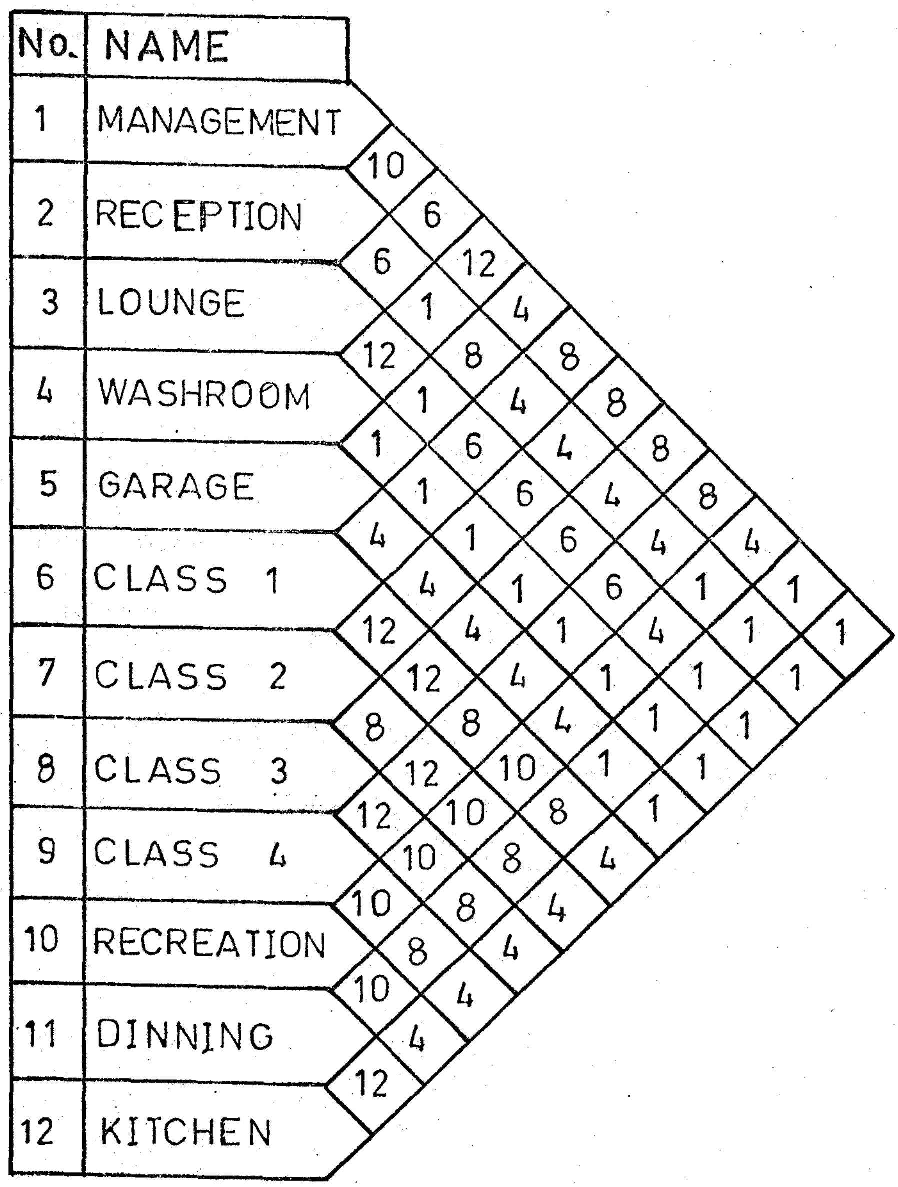


Figure: 37

OPTIMUM PLAN LAYOUT USING THE NEGHBOURING TECHNIGUE

****

NUMBER OF ROOMS TO BE LOCATED....................N = 12

LAND LENGTH.......................................XL = 120.000 FEET

LAND WIDTH..YL = 120.000 FEET

INITIAL SPATIAL CONFIGURATICN OF EACH ROOM

NO.	NAME	LENGTH(FEET)	WIDTH(FEET)	AREA	EXPOSURE	DIRECTION
1	MANAGEMENT	0.00	0.00	200.00	0	0
2	RECEIPTION	0.00	0.00	150.00	0	0
3	LAOUNGE	0.00	0.00	200.00	0	0
4	WASHROOM	15.00	10.00	150.00	0	0
5	GARAGE	20.00	10.00	200.00	0	0
6	CLASS 2	0.00	0.00	400.00	0	0
7	CLASS 3	0.00	0.00	400.00	0	0
8	CLASS 4	0.00	0.00	400.00	0	0
9	CLASS 5	0.00	0.00	400.00	0	0
10	RECREATION	30.00	20.00	600.00	0	0
11	DINNING	30.00	20.00	600.00	0	0
12	KITCHEN	20.00	15.00	300.00	0	0

Computer Output:17

REFERENCE FILES

****

ORDERED SEQUENCE OF ROOMS ACCORDING TO DECREASING TCR

ROOM NO.	AREA	LENGTH	WIDTH	TCR
6	36	6	6	77
7	36	6	6	77
8	36	6	6	77
9	36	6	6	77
1	20	5	4	70
10	54	9	6	68
11	54	9	6	59
3	20	5	4	55
2	16	4	4	44
12	30	6	5	37
5	18	6	3	36
4	15	5	3	33

**NOTE BOTH LENGTH AND WIDTH ARE REPRESENTED IN MODULES
ONE MODULE = 40 INCHES

SIZE OF THE LAYOUT MATRIX

NUMBER OF ROWS = 35
NUMBER OF COLUMNS= 35

Computer Output : 18

SEQUENCE OF WINNERS

NC.	ROOM NO.
1	6
2	7
3	8
4	9
5	10
6	11
7	1
8	3
9	2
10	12
11	5
12	4

Computer Output : 18 (cont.)

FINAL PLAN LAYOUT

Computer Output:19

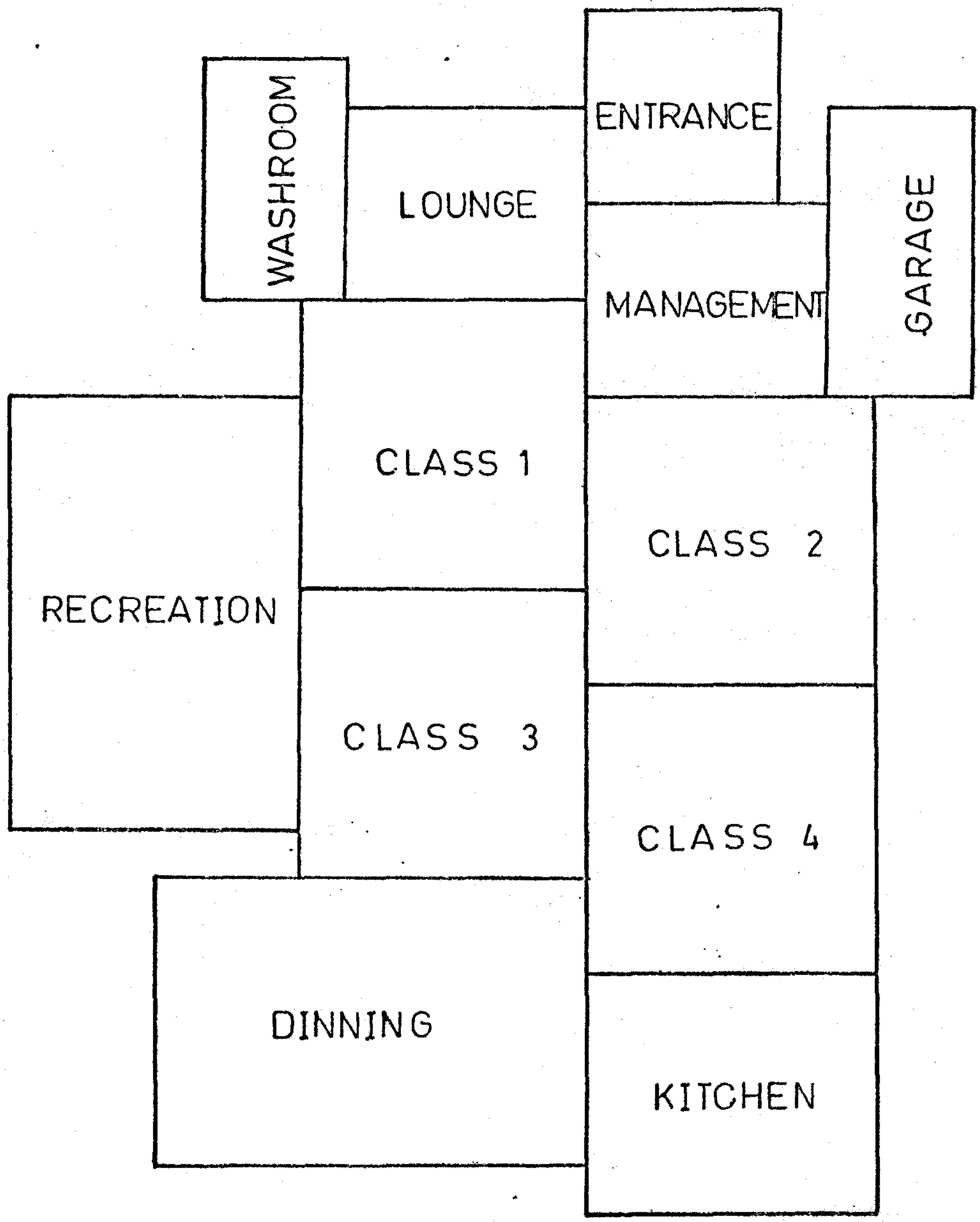
0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	4	4	4	0	0	0	0	0	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	4	4	4	3	3	3	3	3	2	2	2	2	0	5	5	5	0	0	0	0	0	0	0
0	0	0	0	0	0	4	4	4	3	3	3	3	3	2	2	2	2	0	5	5	5	0	0	0	0	0	0	0
0	0	0	0	0	0	4	4	4	3	3	3	3	3	1	1	1	1	1	5	5	5	0	0	0	0	0	0	0
0	0	0	0	0	0	4	4	4	3	3	3	3	3	1	1	1	1	1	5	5	5	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	9	9	9	9	9	9	1	1	1	1	1	5	5	5	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	9	9	9	9	9	9	1	1	1	1	1	5	5	5	0	0	0	0	0	0	0
0	0	10	10	10	10	10	10	9	9	9	9	9	9	7	7	7	7	7	7	0	0	0	0	0	0	0	0	0
0	0	10	10	10	10	10	10	9	9	9	9	9	9	7	7	7	7	7	7	0	0	0	0	0	0	0	0	0
0	0	10	10	10	10	10	10	9	9	9	9	9	9	7	7	7	7	7	7	0	0	0	0	0	0	0	0	0
0	0	10	10	10	10	10	10	9	9	9	9	9	9	7	7	7	7	7	7	0	0	0	0	0	0	0	0	0
0	0	10	10	10	10	10	10	8	8	8	8	8	8	7	7	7	7	7	7	0	0	0	0	0	0	0	0	0
0	0	10	10	10	10	10	10	8	8	8	8	8	8	7	7	7	7	7	7	0	0	0	0	0	0	0	0	0
0	0	10	10	10	10	10	10	8	8	8	8	8	8	6	6	6	6	6	6	0	0	0	0	0	0	0	0	0
0	0	10	10	10	10	10	10	8	8	8	8	8	8	6	6	6	6	6	6	0	0	0	0	0	0	0	0	0
0	0	10	10	10	10	10	10	8	8	8	8	8	8	6	6	6	6	6	6	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	8	8	8	8	8	8	6	6	6	6	6	6	0	0	0	0	0	0	0	0	0

(continued)

0	0	0	0	0	11	11	11	11	11	11	11	11	11	6	6	6	6	6	6	0	0	0	0	0	0	0	0	0
0	0	0	0	0	11	11	11	11	11	11	11	11	11	6	6	6	6	6	6	0	0	0	0	0	0	0	0	0
0	0	0	0	0	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	0	0	0	0	0	0	0	0	0
0	0	0	0	0	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	0	0	0	0	0	0	0	0	0
0	0	0	0	0	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	0	0	0	0	0	0	0	0	0
0	0	0	0	0	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	12	12	12	12	12	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

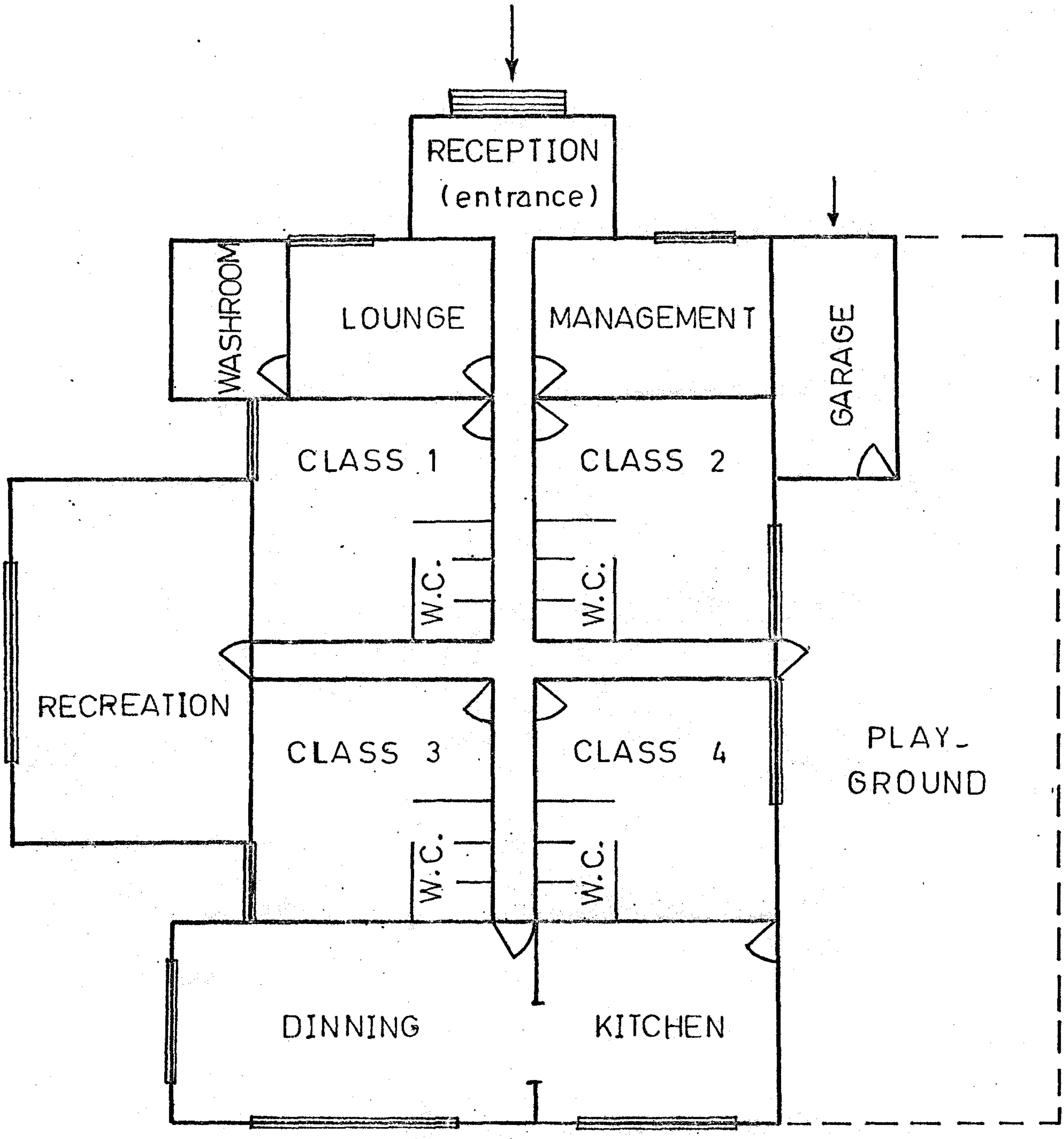
* THE SCORE OF THIS LAYOUT IS = 277.5290
* NOTE THE LESS THE SCORE THE BETTER THE LAYOUT

Computer Time = 19.72 seconds



Computer Plan Layout

Figure: 38



Adjusted Plan Layout

Figure: 39

6.7 CONCLUSION:

This technique is a very good technique as far as formulation and transformation into a working floor plan are concerned.

Although the accomodations in this study have been mainly identified as rooms, the same approach is equally applicable in any design of industrial, commercial, and institutional buildings.

Obviously, there must be some limit to the size of layout which can reasonably be dealt with by this computer program. However, modifications can easily be made to deal with larger design problems. It is likely that with larger complexes, some very closely related rooms could be combined and/or the size of the unit area to be manipulated could reasonably be increased, thereby reducing the necessary number of calculations and keeping the problem within economical limits.

The last consideration is whether or not the solution obtained by applying this approach is worth the effort. The solutions developed do provide an excellent relative layout scheme upon which the architectural solution can grow. Also, it enables the architect and the client to make accurate value judgements regarding the alternatives available to them in the design process. The value of using this computer program can be better appreciated when we note the cost and time needed to apply this approach compared with the cost and time required using the traditional method of design.

CHAPTER VII

CONCLUSION AND INDICATIONS FOR POSSIBLE FURTHER DEVELOPMENT

7.1 CONCLUSION:

This section will serve to review what the main contributions are of this thesis.

First, a new prefabrication housebuilding system is proposed, which, it is believed, satisfies many of the requirements of an ideal housing system. It combines many of the features of the existing system and is considered evolutionarily compatible with the currently used house building system. The modular system is used in planning; and this system uses standardized sections of all the building units which could be used in any plan design, preserving design flexibility and providing an efficient use of the material.

The computerization of house plans based on this system of house-building is achieved through the use of the program developed in this thesis, which is a user oriented program that designs the optimum house configurations, given the user constraints, such as room areas and exposure directions. It is believed that this program represents a significant break-through in the concept of computer-aided design.

One very important feature of the methodology of this program is that it uses quantitative data, but also provides a means for qualitative information to be combined with quantitative data by using the Relationship Chart prior to entering the computerized phase. Upon entering the computer, the processing of the data is guided by an algorithm which insures a layout that approaches in a positive manner, a superior block layout.

This thesis developed only a part of the total achievements possible in computerized house design using relationship planning. However, it did substantiate that computers can analyze inter-relationships between the different rooms and produce a very good plan layout in a small fraction of the time and costs presently required by use of conventional techniques.

7.2 INDICATIONS FOR POSSIBLE FURTHER DEVELOPMENT:

Some logical extensions of the search done in this thesis are given below.

7.2.1 Three Dimensional Problems

The program is written for a two dimensional layout (single story houses). A two dimensional solution was selected for two reasons. First, to show that the basic problem of computerizing house design could be solved and secondly because a great portion of houses, especially those of small and medium sizes, are usually of single story design.

A solution for the three dimensional problem might be quite readily obtained by making the layout matrix [LAY(I, J)] a three dimensional matrix [LAY(I, J, M)]. This would require that the value of closeness for space adjacent, but on the floor above or below, be different from the value of closeness on the same floor. Three dimensional analysis would be done, and then the placement of rooms would be limited to the I, J (horizontal plane), once a floor selection was made.

7.2.2 Detailed Plotting of the Final Adjusted Layout

It would be useful to develop a computer program that, given the necessary data about the final adjusted floor plan, would plot a detailed drawing to scale for the plan layout showing doors, windows, closets, storage shelves and stairs. This would save of the drawing time and costs.

7.2.3 Layout Evaluation

A valid method of cost evaluation of the final adjusted layout within the computer, based on the lengths of the exterior walls and the number of windows and doors needed, coupled with a re-estimation of the summation of the weighted center distances for the adjusted plan layout, would provide two important services. First, a means of comparing any final adjusted layout with any alternative final adjusted layout. This would provide valuable information in selecting the best final layout. Second, it would provide a means of comparing a given layout with the "ideal" layout as might be obtained from the Relationship Chart without considering space requirement restrictions.

7.2.4 Interactive Relationship Layout Planning

A similar program would be possible using the same heuristic algorithm. The only difference would be the use of interaction between the user and the heuristic logic. Using a time-shared computer system or a cathode-ray screen and pen, the user could modify a layout at any time, thus assisting the heuristic algorithm in its design effort.

7.2.5 Structural and Cost Analysis

A computer program may be developed that, given a final outline, prepares a set of detailed drawings (working drawings) to scale, a bill of the required materials units, a work schedule and a cost breakdown and price. This would give the user a more clear picture of his project.

BIBLIOGRAPHY

(1) Alexander, Christopher: "HIDECS3, Four Computer Programs for the Hierarchical Decomposition of Systems which have an Associated Linear Graph", Research Report R63-27, Department of Civil Engineering, M.I.T., Cambridge, Massachusetts.

(2) Alexander, Christopher: "Notes on the Synthesis of Form", Harvard Press, Cambridge, Massachusetts, 1964.

(3) Anderson, Thomas R.: "Layout Planning for Minimum Circulation Cost", Unpublished M.S. Thesis, Seattle, Washington, Library, University of Washington, 1965.

(4) Armour, Gordon C. and Buffa, Elwood S.: "A Heuristic Algorithm and Simulation Approach to Relative Location of Facilities", Management Science, January 1963, Vol. 9, No. 1, pp. 294-309.

(5) Buffa, Elwood S., Armour, Gordon C., and Vollmann, Thomas E.: "Allocating Facilities with CRAFT", Harvard Business Review, March-April 1964, Vol. 42, No. 2, pp. 136-195.

(6) Campion, David: "Computers in Architectural Design", Elsevier, Amsterdam, 1968.

(7) Edward Bierston and Allen Bernholtz: "HIDECS-RECOMP Procedure", A Report obtained from the Department of Civil Engineering, M.I.T., Cambridge, Massachusetts, 1967.

(8) Grason, J.: "Methods for Computer-Implemented Solution of a Class of Floor Plan Design Problems", Ph.D. Thesis, Carnegie-Mellon University, Pennsylvania, May 1970.

(9) Henry J. Cowan: "An Historical Outline of Architectural Science", Architectural Science Series, Elsevier, New York, 1966.

(10) James N. Siddal: "Analytical Decision Making in Engineering Design", In Print, Prentice-Hall, 1971.

(11) Lee, K.: "The Computer as an Architectural Design Tool; An Exploration into Certain Multi-Story Building Plan Layouts", M.Arch. Thesis, Iowa State University, Iowa, 1969.

(12) Leone Battista Alberti (translated by J. Leoni): "Ten Books on Architecture", Alec Tiranti, London, 1955.

(13) Lewicki, Bohdan: "Building with Large Prefabricates", Elsevier, New York, 1966.

(14) Marcus Vitruvius Pollio (translated by M. H. Morgan): "The Ten Books of Architecture", Dover Publications, New York, 1960.

(15) Mosely, Lynn: "A Rational Design Theory for Planning Buildings Based on the Analysis and Solution of Circulation Problems", Architect's Journal, September 11, 1963, Vol. 138, No. 10, pp. 525-537.

(16) Muther, Richard D.: "Systematic Layout Planning", Industrial Education Institute, Boston, 1961.

(17) Parsons, William H.: "A Comparative Analysis of Space Allocation Techniques", M.S. Thesis, Northeastern University, May 1966.

(18) Parsons, David: "Performance Design-Planning by Numbers", Progressive Arch., August 1967, Vol. 58, No. 8, pp. 103-153.

(19) Robert C. Lee: "Computerized Relationship Layout Planning-CORELAP", M.S. Thesis, Northeastern University, May 1966.

(20) Stewart, C.D., Teicholz, E. and Lee, K.: "Computer Architecture Programs - CAP", Center for Environmental Research, Boston, 1970.

(21) Simon, Herbert A.: "The Sciences of the Artifacts", M.I.T. Press, 1969.

(22) Wheeler, L. W. and Millter, E. H.: "Comprehensive Architectural Practice-Human Factors Analysis", Am. Inst. Arch. J., December 1963, Vol. 40, No. 6, pp. 43-49.

(23) Whitehead, B. and Eldars, M.Z.: "An Approach to the Optimum Layout of Single-Story Buildings", Arch. J., June 17, 1964, Vol. 139, No. 25, pp. 1373-1380.

(24) --------: "Innovation in Building", Edited by the International Council for Building Research, Studies and Documentation - CIB, Elsevier, New York, 1962.

(25) --------: "Social Aspects of Prefabrication in the Construction Industry", Report prepared by The International Labour Office, Geneva, 1968, 119 p., N.R.C. Library in Canada.

A P P E N D I C E S

APPENDIX A

TERMINOLOGY

TERMINOLOGY	DEFINITION
N	Number of rooms.
XL	Land length.
YL	Land width.
X(I)	Length of the ith room.
Y(I)	Width of the ith room.
A(I)	Area of the ith room.
XNAME(I)	Name of the ith room.
UNAME	User's name.
IDRC1(I)	Exposure direction number 1 of the ith room.
IDRC2(I)	Exposure direction number 2 of the ith room.
WAIT(I)	Vector for storing one half of the relationship matrix.
CLOSE(I, J)	Relationship matrix.
MX(I)	Modular length of the ith room [in units].
MY(I)	Modular width of the ith room [in units].
MXY(I)	Modular area of the ith room [in units].
TCR(I)	Total closeness rating of the ith room which equals the sum of all the closeness ratings for a certain room with the rest of the rooms.
ID	Number of rows in the layout matrix.

TERMINOLOGY	DEFINITION
JD	Number of columns in the layout matrix.
PRIOR(I)	Priority of the ith room.
WIN(I)	The WINNER number I.
TOTAL	The total of the closeness ratings of a certain group of rooms with the remaining rooms.
L	Counter with values going from 1 to N.
LAY(I, J)	Layout matrix.
LAYW(I, J) LAYR(I, J)	Working layout matrices.
CG(I)	The position of the center of the ith room.
CD	Center-distance between two rooms.
SUMA	The sum of the weighted center-distances.

The subscripts I and J are used to identify rooms or locations in any matrix in both the thesis discussion and the actual program, in the conventional manner (I identifies the row and J identifies the column of the matrix). Additionally, numerous synonyms had to be used in the program to represent I and J to avoid confusion between routines.

APPENDIX B

RELATIONSHIP CHARTS

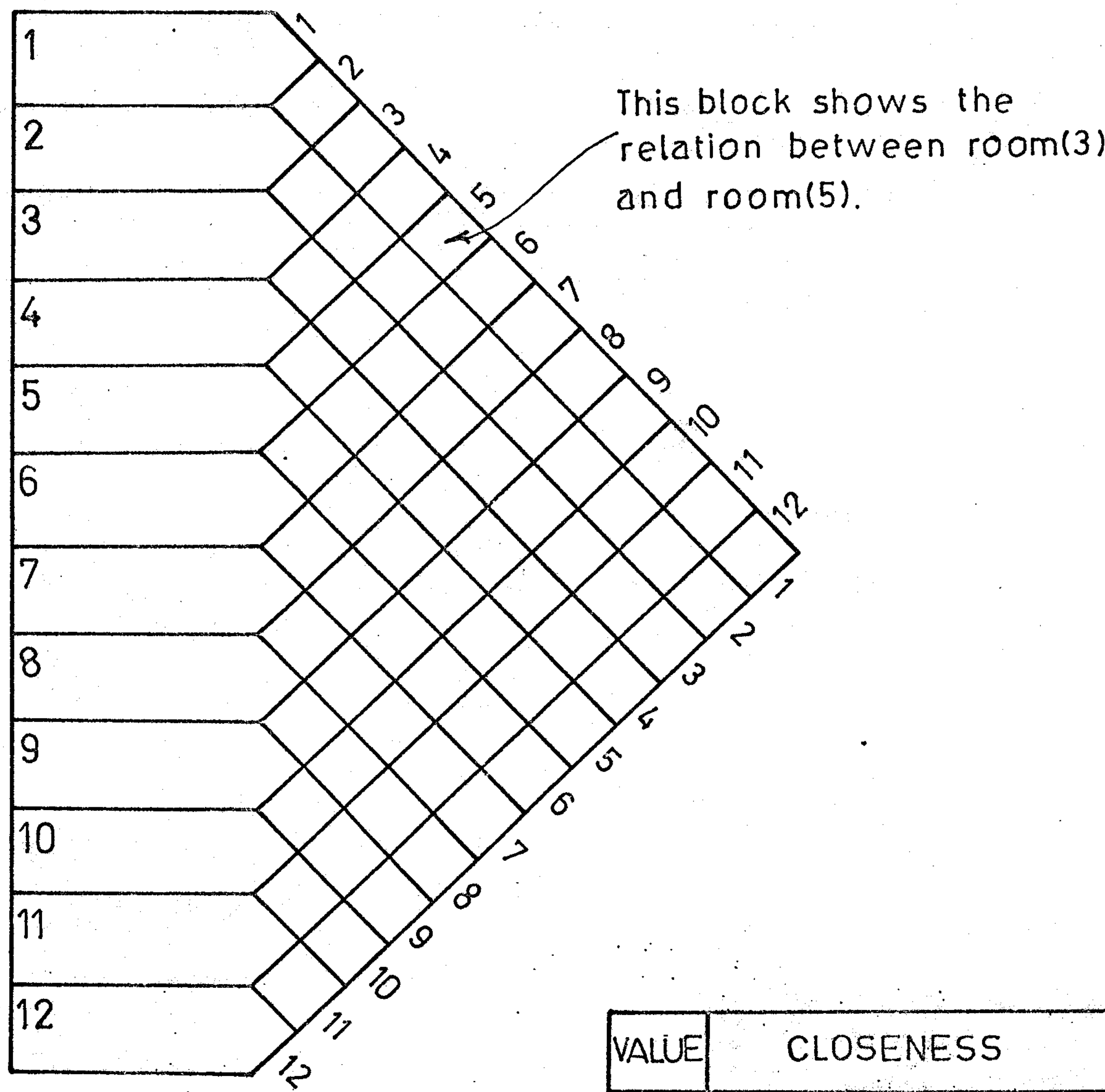
A very effective and probably the best way of representing the relationships and closeness ratings between the different rooms is to use a Relationship Chart constructed by Richard Muther and Associates. The Relationship Chart will show in a clear way the magnitude of the relationship between the different rooms.

The chart itself is nearly self-explanatory. Each pair of rooms must be considered and the appropriate value of closeness placed in the box common to both rooms according to the suggested set of ratings, the result is a condensed display of all-inter-relationships. The following figure shows an example of a Relationship Chart and the set of ratings used in this thesis.

A set of typical reasons supporting closeness ratings when designing a house are:

1. Degree of communication.
2. Use of same facilities.
3. Specific privacy requirements.
4. Noise, dirts, dust, fumes.
5. Disturbance or interruptions.
6. Flow of personnel or material.

RELATIONSHIP CHART



VALUE	CLOSENESS
12	Absolutely Necessary.
10	Especially Important.
8	Important.
6	Ordinary Close.
4	Unimportant.
1	Undesirable.

Figure : 40

APPENDIX C

THE USERS' MANUAL

The program described in this users' manual is one of a large package presenting how computers can aid design. This package is designed to provide unsophisticated and easily optimization subroutines for designers.

```
SUBROUTINE OCREPL(N, NN, IDATA, INTRMD, IREF, XNAME,
                  X, Y, A, WAIT, CLOSE, MX, MY, MXY, TCR,
                  PRIOR, WIN, IWIN, TOTAL, CG, CGF, CD,
                  TCR1, IDRC1, IDRC2, XL, YL, UNAME)
```

PURPOSE

To design the optimum house configuration, based on the modular system in planning the house plan layout, given the user's constraints regarding the room areas and the exposure directions.

METHOD

The technique used in this program is an "Additive Function Technique" (where the function in this case means a room). The rooms are to be placed one by one on the plan layout grid, according to a list of priorities to be established prior to the placing, minimizing the weighted center-distance between the different pairs of rooms. The relationships or the closeness ratings between the different rooms are used as the basic criterion for the layout arrangement. The procedure consists of a systematic, heuristic, non-exhaustive search which allows a steady growth of the optimum plan layout. The design method could be summarized as follows:

A. Establishing the Reference Files

1. The most suitable modular dimensions and area for each room is determined.

2. The size of the layout matrix is established.

3. A relationship matrix is established which represents the inter-relationships between the different rooms.

4. The total closeness rating (TCR) for each room is computed and the rooms are ranked according to its TCR in a decreasing order.

5. The sequence in which the rooms will enter the layout matrix is established.

B. Locating the Rooms in the Layout Matrix

The most important room is placed in the center of the layout matrix, then the rooms are placed one by one in the layout matrix according to the previously established sequence. Each time a new room is placed a sub-optimization problem is solved to determine the optimum position of this room which minimizes the sum of the weighted center-distances between the new room and the previously located rooms. The user's constraints for the exposure directions are taken into consideration when selecting any position for any room.

INPUT DATA

XL	Land length (feet).	Set at zero for no specified land configuration.
YL	Land width (feet).	
UNAME	User's name, not to be greater than six characters.	

XNAME(I)	Name of the ith room, dimensioned with the value of N, not to be greater than 10 characters.
X(I)	Length of the ith room (feet), dimensioned with the value of N, set at zero for no length specification.
Y(I)	Width of the ith room (feet), dimensioned with the value of N, set at zero for no width specification.
A(I)	Area of the ith room (square feet), dimensioned with the value of N.
IDRC(1(I)	Exposure direction number 1 of the ith room, dimensioned with the value of N, set at zero for no exposure direction specification.
IDRC2(I)	Exposure direction number 2 of the ith room, dimensioned with the value of N, set at zero for no exposure direction specification.
WAIT(I)	Closeness rating between the different rooms, dimensioned with the value of NN.

<u>INPUT VARIABLES</u>

N	Number of rooms.
NN	Set equal to $(N^2 - N)/2$
IDATA	= 1, all input data is printed out. = 0, input data is not printed out.
IREF	= 1, all computed reference files are printed out. = 0, reference files are not printed out.
INTRMD	= 1, an intermediate plan layout in matrix format is printed out after placing each room. = 0, intermediate layouts are not printed out.

<u>WORKING ARRAYS</u>

CLOSE	dimensioned with the value of (N, N)
MX	dimensioned with the value of (N)

MY	dimensioned with the value of (N)
MXY	dimensioned with the value of (N)
TCR	dimensioned with the value of (N)
TCR1	dimensioned with the value of (N)
PRIOR	dimensioned with the value of (N)
WIN	dimensioned with the value of (N)
IWIN	dimensioned with the value of (N)
TOTAL	dimensioned with the value of (N)
CG	dimensioned with the value of (N)
CGF	dimensioned with the value of (N)
CD	dimensioned with the value of (N)

OUTPUT VARIABLES

SCORE	The value of the total summation of the weighted center-distances will always be printed with the final layout. This is considered as an evaluation of this layout and would help in comparing it with any other possible layout. The less this value is, the better the layout will be.

PROGRAMMING INFORMATION

Subroutine OCREPL has full variable dimensioning. The calling program must provide dimensioning as given above.

The final plan layout in matrix format and also the graph plotting are printed out directly from OCREPL.

A plot tape (TAPE10) should be assigned in the main program in the following way:

```
PROGRAM TST (INPUT, OUTPUT, TAPE5 = INPUT, TAPE6 = OUTPUT, TAPE10).
```

Also, the user should add (TP1) on his job card as follows:

```
A1234, CM     , T     , TP1.                    J. USER
```

Subroutine OCREPL is kept in the permanent files and according to the ID system currently used in the computing center of McMaster University for the use of permanent files, the following ATTACH and LOAD cards are required as control cards:

```
ATTACH(FILE1, OCREPL, ID.= HVSHODA, CY = 1)
LOAD(FILE1).
```

If no available space is found for any room, an error message will be printed out and OCREPL exits without return.

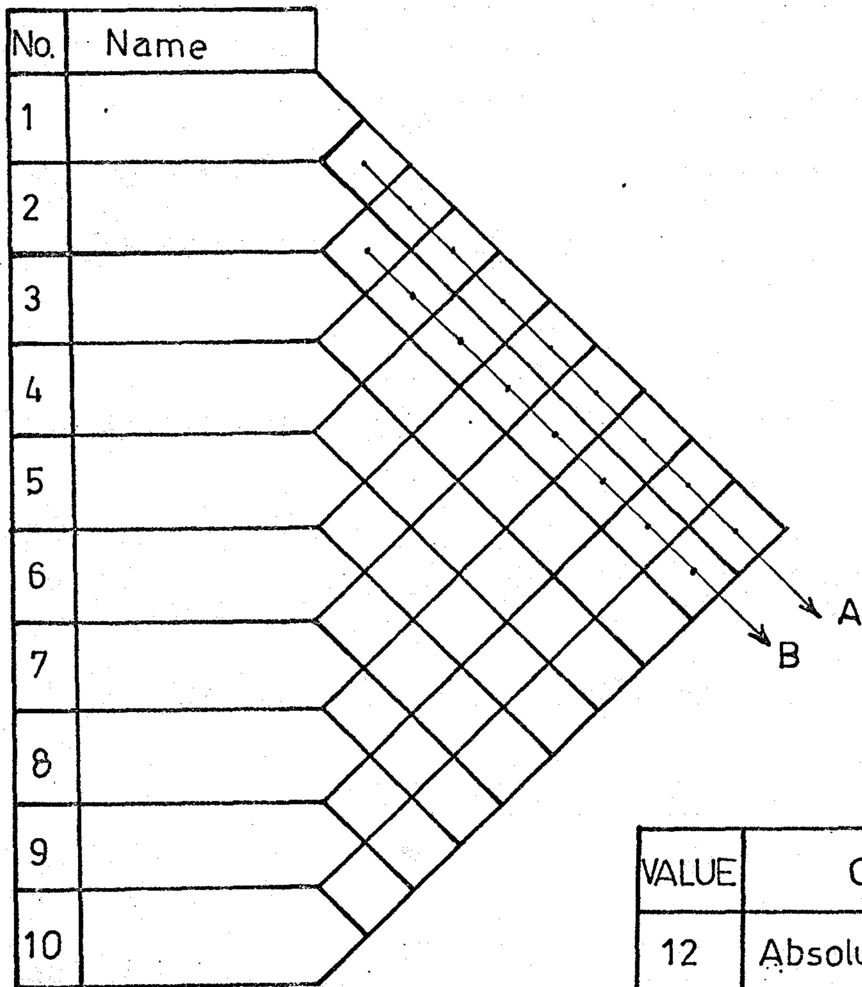
The user is encouraged to run the program without any constraints on the building land configuration at first; to obtain the ideal layout, then run it once more with any necessary constraints.

Subroutines called are CALC, RANK, AMR, AMR2, LOCATE, PLAN1, PLAN2 and PLAN3.

HOW TO CONSTRUCT THE RELATIONSHIP CHART

The user must provide closeness ratings that represent how he feels rooms should ideally relate to each other, using the set of values given in the following table (Figure 41) to fill up the Relationship Chart.

These values must be given as input data in the form of a vector [WAIT(I)] beginning with the relations between the first room and the rest of the rooms (reading in the direction of arrow A), then the relations between the second room and the rooms number 3, 4, ..., N (reading in the direction of arrow B). The process continues until all the relationships are given.



VALUE	CLOSENESS
12	Absolutely Necessary
10	Especially Important
8	Important
6	Ordinary Close
4	Unimportant
1	Undesirable

Figure: 41

USING THE RELATIONSHIP CHART

EXPOSURE DIRECTION SPECIFICATION

The user can specify any exposure direction he wants for any room as input data with a maximum of two directions for each room [IDRC1(I), IDRC2(I)], taking into consideration the position of his land relative to the surroundings and knowing that the produced plan layout will always have:

- the top as direction number 1.
- the righthand side as direction number 2.
- the bottom as direction number 3.
- the lefthand side as direction number 4.

If the user wants the room number 5 to have the exposure direction number 2 free, then he must set IDRC1(5) at 2, and if, at the same time, he wants the same room to have the exposure direction number 3 free, then he must set IDRC2(5) at 3. The exposure directions are shown in Figure .

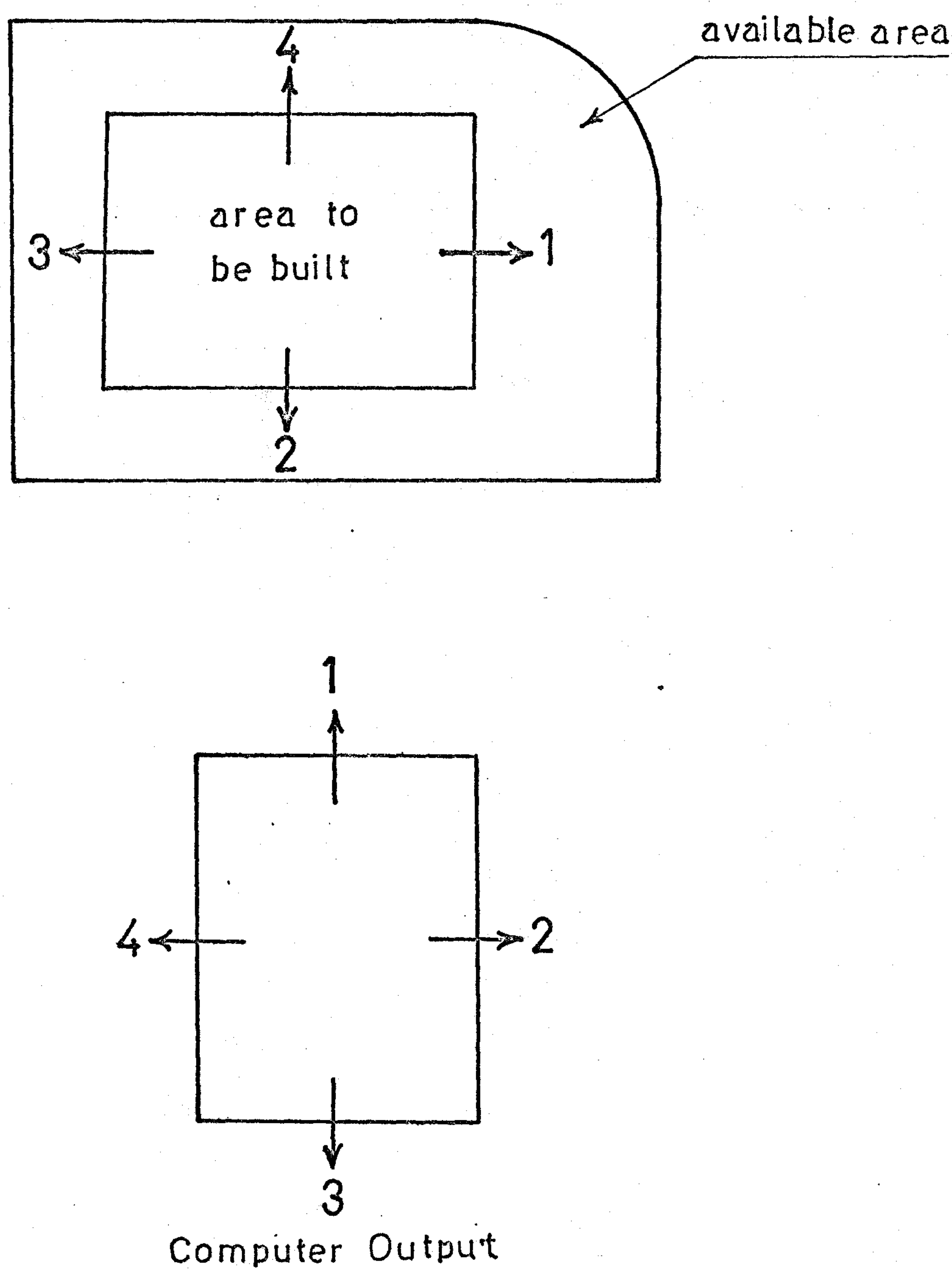


Figure: 42

EXPOSURE DIRECTIONS

A Calling Program

```
      PROGRAM TST (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE10)
      DIMENSION XNAME(9),X(9),Y(9),A(9),WAIT(36),CLOSE(9,9),MX(9),MY(9),
     $MXY(9),TCR(9),PRIOR(9),WIN(9),TOTAL(9),IDRC1(9),IDRC2(9),IWIN(9),
     $CG(9),CGF(9),CD(9),TCR1(9)
      COMPLEX CG, CGF
C
      N=9
      NN=36
      IDATA=1
      INTRMD=1
      IREF=1
      XL=0.0
      YL=0.0
      DATA UNAME/6HHODA H/
      DATA XNAME/5HBED 1,5HBED 2,5HBED 3,6HBATH 1,6HBATH 2,6HLIVING,7HDI
     $NING,7HKITCHEN,6HGARAGE/
      DATA X/10.,10.,10.,0.,0.,20.,10.,10.,17./
      DATA Y/10.,10.,10.,10.,10.,10.,10.,10.,10./
      DATA A/100.,100.,100.,65.,65.,200.,100.,100.,170./
      DATA IDRC1/0,0,0,0,0,1,0,0,0/
      DATA IDRC2/0,0,0,0,0,0,0,0,0/
      DATA WAIT/10.,6.,12.,1.,12.,4. ,1.,1.,12.,12.,4.,1.,1.,1.,1.,4.,12
     $.,4.,6.,1.,1.,4.,6. ,4.,1.,1.,1.,6.,4.,1.,12.,12.,4.,12.,12.,12./
C
      CALL CCREPL(N,NN,IDATA,INTRMD,IREF,XNAME,X,Y,A,WAIT,CLOSE,MX,MY,
     $MXY,TCR,PRIOR,WIN,IWIN,TOTAL,CG,CGF,CD,TCR1,IDRC1,IDRC2,XL,YL,UNAM
     $E)
C
      STOP
      END
```

APPENDIX D

COMPUTER PROGRAM LISTING

THE FOLLOWING IS THE OCREPL PROGRAM LISTING AND THE CALLED SUBROUTINES (814 CARDS) IN FORTRAN IV FOR THE CDC 6400 .

```
      SUBROUTINE OCREPL (N,NN,IDATA,INTRMD,IREF,XNAME,X,Y,A,WAIT,CLOSE,M
     1X,MY,MXY,TCR,PRIOR,WIN,IWIN,TOTAL,CG,CGF,CD,TCR1,IDRC1,IDRC2,XL,YL
     2,UNAME)
C     ****************************************************************
C
C     OPTIMUM COMPUTERIZED RELATIONSHIP PLAN LAYOUT ( OCREPL )
C
C     IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF
C     MASTER OF ENGINEERING
C
C     PROGRAMMED BY HODA EL-GAMMAL ,DEPARTMENT OF MECHANICAL ENGINEERING
C     MCMASTER UNIVERSITY , HAMILTON ,ONTARIO ,CANADA ,AUGUST 1971
C
C     UNDER THE SUPERVISION OF
C     PROFESSOR J.N. SIDDALL , MECHANICAL ENGINEERING
C
C     ****************************************************************
      DIMENSION X(N), Y(N), A(N), XNAME(N), WAIT(NN), MX(N), MY(N), MXY(
     1N), CLOSE(N,N), TOTAL(N), TCR(N), PRIOR(N), WIN(N), IWIN(N), LAY(6
     27,67), LAYW(67,67), CG(N), CGF(N), CD(N), TCR1(N), IDRC1(N), IDRC2
     3(N), LAYR(67,67)
      COMPLEX CG,CGF
C
C     DEFINITION OF THE USED PARAMETERS
C     ---------------------------------
C
C     UNAME = THE NAME OF THE USER
C     N=NUMBER OF ROOMS
C     XL=LAND LENGTH
C     YL=LAND WIDTH
C     X(I)=LENGTH OF THE ITH ROOM
C     Y(I)= WIDTH OF THE ITH ROOM
C     A(I)= AREA OF THE ITH ROOM
C     IDRC1(I)=EXPOSURE DIRECTION NO. 1 OF THE ITH ROOM
C     IDRC2(I)=EXPOSURE DIRECTION NO. 2 OF THE ITH ROOM
C     WAIT= THE RELATIONSHIP BETWEEN EACH PAIR OF ROOMS
C
      N1=N-1
      KK=0
      DO 2 J=1,N1
      N2=J+1
      DO 1 I=N2,N
      KK=KK+1
      CLOSE(I,J)=WAIT(KK)
    1 CONTINUE
    2 CONTINUE
C
C     WRITING THE INPUT DATA (IF IDATA.EQ.1)
C     --------------------------------------
C
      IF (IDATA.NE.1) GO TO 4
      WRITE (6,5)
      WRITE (6,6) N
      WRITE (6,7) XL
      WRITE (6,8) YL
      WRITE (6,9)
      WRITE (6,10)
      WRITE (6,11) ((I,XNAME(I),X(I),Y(I),A(I),IDRC1(I),IDRC2(I)),I=1,N)
      WRITE (6,12)
      WRITE (6,13) ((I),I=1,N)
      II=1
      WRITE (6,14) II
      DO 3 I=2,N
      NJ=I-1
      WRITE (6,15) I,((CLOSE(I,J)),J=1,NJ)
    3 CONTINUE
    4 CONTINUE
C
C     ESTABLISHING THE REFERENCE FILES
C     --------------------------------
C
      CALL CALC (N,X,Y,A,XL,YL,CLOSE,MX,MY,MXY,TCR,TOTAL,PRIOR,WIN,ID,JD
     1,TCR1)
C
C     ESTABLISHING THE PLAN LAYOUT
C     ----------------------------
C
```

```
      CALL LOCATE (ID,JD,MX,MY,N,INTRMD,CLOSE,WIN,IWIN,LAY,LAYW,CG,CGF,C
     1D,IDRC1,IDRC2,LAYR,XNAME,UNAME)
      RETURN
C
C
5     FORMAT (1H1,10X,*OPTIMUM PLAN LAYOUT USING THE NEGHBOURING TECHNIQ
     1UE *,//,11X,51(1H*),//)
6     FORMAT (1H0,*NUMBER OF ROOMS TO BE LOCATED...................N
     1=*,4X,I2)
7     FORMAT (1H0,*LAND LENGTH..................................XL
     1=*,F10.3,5X,*FEET*,/)
8     FORMAT (1H0,*LAND WIDTH...................................YL
     1=*,F10.3,5X,*FEET*,/)
9     FORMAT (1H0,10X,*INITIAL SPATIAL CONFIGURATION OF EACH ROOM*,/,11X
     1,21(2H--),//)
10    FORMAT (1H0,*NO.            NAME              LENGTH(FEET)     WIDTH(FEET
     1)       AREA          EXPOSURE DIRECTION*,//)
11    FORMAT (I3,10X,A10,7X,F6.2,2(10X,F6.2),2(8X,I3),/)
12    FORMAT (1H0,10X,*THE RELATIONSHIP CHART*,/,11X,11(2H--),/)
13    FORMAT (1H0,5X,26I5)
14    FORMAT (1H0,3X,I1,4X,26I5)
15    FORMAT (1H ,I4,2X,26F5.0,/)
      END
```

CD TOT 0100

```
      SUBROUTINE CALC (N,X,Y,A,XL,YL,CLOSE,MX,MY,MXY,TCR,TOTAL,PRIOR,WIN
     1,ID,JD,TCR1)
      DIMENSION X(N), Y(N), A(N), MX(N), MY(N), MXY(N), CLOSE(N,N), TCR(
     1N), PRIOR(N), WIN(N), TOTAL(N), TCR1(N)
C     ****************************************************************
C
C     THIS SUBROUTINE CALCULATES THE MODULAR DIMENSIONS OF EACH ROOM AND
C     ESTABLISHES THE RELATIONSHIP MATRIX AND
C     DETERMINES THE SIZE OF THE LAYOUT MATRIX
C
C     ****************************************************************
C
C     DETERMINING THE DIMENSIONS OF THE ROOMS IN MODULAR UNITS
C     --------------------------------------------------------
C
      ZERO=0.0
      DO 6 I=1,N
      IF (X(I).EQ.ZERO.AND.Y(I).EQ.ZERO) GO TO 3
      IF (X(I).EQ.ZERO) GO TO 1
      IF (Y(I).EQ.ZERO) GO TO 2
      GO TO 5
1     X(I)=A(I)/Y(I)
      GO TO 5
2     Y(I)=A(I)/X(I)
      GO TO 5
3     XI=SQRT(A(I))*12./40.
      MX(I)=IFIX(XI)
      MY(I)=MX(I)
4     AAI=A(I)*144.0
      AI=FLOAT(MX(I))*FLOAT(MY(I))*1600.0
      DIF=ABS(AI-AAI)
      IF (DIF.LE.0.1*AAI) GO TO 6
      MX(I)=MX(I)+1
      AI=FLOAT(MX(I))*FLOAT(MY(I))*1600.0
      DIF=ABS(AI-AAI)
      IF (DIF.LE.0.1*AAI.OR.AI.GT.AAI) GO TO 6
      MY(I)=MY(I)+1
      GO TO 6
5     MX(I)=IFIX(X(I)*12./40.)
      MY(I)=IFIX(Y(I)*12./40.)
      GO TO 4
6     CONTINUE
      DO 7 I=1,N
      MXY(I)=MX(I)*MY(I)
7     CONTINUE
      ISUM=0
      DO 8 I=1,N
      ISUM=ISUM+MXY(I)
8     CONTINUE
C
C     ESTABLISHING THE SIZE OF THE LAYOUT MATRIX
C     ------------------------------------------
C
      IF (XL.EQ.0.AND.YL.EQ.0) GO TO 9
      IF (XL.EQ.0) GO TO 11
      IF (YL.EQ.0) GO TO 13
      YL=YL*12.0/40.
      JD=IFIX(YL)
      XL=XL*12.0/40.
      ID=IFIX(XL)
      GO TO 15
9     IISUM=0
      DO 10 I=1,N
      IISUM=IISUM+MX(I)+MY(I)
10    CONTINUE
      ID=IISUM/3
      JD=ID
      GO TO 15
11    IISUM=0
      DO 12 I=1,N
      IISUM=IISUM+MX(I)
12    CONTINUE
      ID=IISUM*(2/3)
      YL=YL*12.0/40.0
      JD=IFIX(YL)
      GO TO 15
13    IISUM=0
```

```
      DO 14 I=1,N
      IISUM=IISUM+MY(I)
14    CONTINUE
      JD=IISUM*(2/3)
      XL=XL*12.0/40.0
      ID=IFIX(XL)
      GO TO 15
15    CONTINUE
C
C     CHECK THE CORRECTNESS OF THE COMPUTED DIMENSIONS
C     ------------------------------------------------
C
      IJD=ID*JD
      IF (ISUM.GE.IJD) GO TO 16
      GO TO 17
16    WRITE (6,41)
      STOP 2
17    CONTINUE
      IF (JD.GT.50) GO TO 18
      GO TO 19
18    WRITE (6,50)
      STOP 3
19    CONTINUE
C
C     ESTABLISHING THE RELATIONSHIP MATRIX
C     ------------------------------------
C
      DO 20 J=1,N
      CLOSE(J,J)=0.0
      DO 20 I=1,N
      CLOSE(J,I)=CLOSE(I,J)
20    CONTINUE
C
C     COMPUTING THE TOTAL CLOSENESS RATING FOR EACH ROOM
C     --------------------------------------------------
C
C     TCR  =TOTAL CLOSENESS RATING
C          =SUM OF ALL THE CLOSENESS RATING FOR A CERTAIN ROOM WITH THE
C           REST OF THE ROOMS
C
      DO 22 I=1,N
      TCR(I)=0.0
      DO 21 J=1,N
      TCR(I)=TCR(I)+CLOSE(I,J)
21    CONTINUE
22    CONTINUE
C
C     RANKING  TCR IN A DECREASING ORDER
C     ----------------------------------
C
      CALL RANK (N,TCR,PRIOR,TCR1)
C
C     ESTABLISHING THE SEQUENCE IN WHICH THE ROOMS WILL ENTER THE LAYOUT
C     ------------------------------------------------------------------
C
C
C     DETERMINING THE FIRST WINNER
C     ----------------------------
C
C     WIN(I) = THE ITH WINNER
C     PRIOR = PRIORITY IN WHICH THE WINNER WILL ENTER THE LAYOUT MATRIX
C
      L=1
      WIN(1)=PRIOR(1)
      IK=IFIX(WIN(1))
      DO 23 J=1,N
      TOTAL(J)=CLOSE(IK,J)
23    CONTINUE
C
C     DETERMINING THE MOST RELATED ROOMS TO THE FIRST WINNER
C     ------------------------------------------------------
C
      CALL AMR (IK,N,CLOSE,L,WIN)
      DO 25 J=1,N
      DO 24 I=2,L
```

```
      K=IFIX(WIN(I))
      TOTAL(J)=TOTAL(J)+CLOSE(K,J)
24    CONTINUE
25    CONTINUE
      DO 26 I=1,L
      K=IFIX(WIN(I))
      TOTAL(K)=0.0
26    CONTINUE
C
C     DETERMINE SUBSEQUENT WINNERS
C     ----------------------------
C
27    KC=0
28    IF (L.EQ.N) GO TO 38
C
      CALL AMR2 (N,TOTAL,L,WIN,NR)
C
      IF (NR.NE.1) GO TO 29
      K=IFIX(WIN(L))
      TOTAL(K)=0.0
      KC=KC+1
      GO TO 28
29    IF (KC.NE.0) GO TO 34
C
C     SELECTING THE NEXT WINNER IF ALL THE TCR ARE EQUAL (NO PREVIOUS
C     WINNERS
C     ---------------------------------------------------------------
C
      LNR=L-NR+1
      DO 31 K=1,N
      DO 30 M=LNR,L
      IF (WIN(M).NE.PRIOR(K)) GO TO 30
      WIN(LNR)=PRIOR(K)
      GO TO 32
30    CONTINUE
31    CONTINUE
32    L=LNR
      K=IFIX(WIN(L))
      DO 33 J=1,N
      TOTAL(J)=TOTAL(J)+CLOSE(K,J)
33    CONTINUE
      TOTAL(K)=0.0
      GO TO 27
C
C     CASE OF EQUAL TCR WITH PREVIOUS WINNERS
C     ---------------------------------------
C
34    L=L-NR
      LC=L-KC+1
      DO 36 J=1,N
      DO 35 I=LC,L
      K=IFIX(WIN(I))
      TOTAL(J)=TOTAL(J)+CLOSE(K,J)
35    CONTINUE
36    CONTINUE
      DO 37 I=1,L
      K=IFIX(WIN(I))
      TOTAL(K)=0.0
37    CONTINUE
      GO TO 27
C
C     WRITING THE REFERENCE FILES (IF IREF.EQ.1)
C     ------------------------------------------
C
38    IF (IREF.EQ.0) GO TO 40
      WRITE (6,42)
      WRITE (6,43)
      WRITE (6,44)
      DO 39 I=1,N
      KO=IFIX(PRIOR(I))
      WRITE (6,45) (KO,MXY(KO),MX(KO),MY(KO),TCR(KO))
39    CONTINUE
      WRITE (6,49)
      WRITE (6,47) ID,JD
      WRITE (6,48)
```

```
      WRITE (6,46) ((KL,WIN(KL)),KL=1,N)
40    CONTINUE
C
      RETURN
C
C
C
41    FORMAT (1H ,* THE SUM OF THE MODULAR AREAS OF ALL THE ROOMS EXCEED
     1ED THE TOTAL MODULAR AREA TO BE BUILT*,/,1X,*RERUN WITH THE NECESS
     2ARY CORRECTIONS IN THE INPUT DATA*)
42    FORMAT (1H1,28X,* REFERENCE FILES *,//,30X,15(1H*),//)
43    FORMAT (1H0,10X,*ORDERED SEQUENCE OF ROOMS ACCORDING TO DECREASING
     1 TCR*,/,11X,53(1H-),//)
44    FORMAT (1H0,*ROOM NO.                AREA             LENGTH             WID
     1TH          TCR*,/)
45    FORMAT (1H0,3X,I2,14X,I3,13X,I2,14X,I2,11X,F4.0)
46    FORMAT (1H ,8X,I2,13X,F3.0,/)
47    FORMAT (//,1H0,10X,* SIZE OF THE LAYOUT MATRIX*,/,12X,25(1H-),///,
     11X,*NUMBER OF ROWS    = *,I3,//,1X,*NUMBER OF COLUMNS= *,I3)
48    FORMAT (//,1H0,10X,* SEQUENCE OF WINNERS*,/,12X,19(1H-),//,10X,*NO
     1.          ROOM NO.*,//)
49    FORMAT (1H0,2H**,*NOTE  BOTH LENGTH AND WIDTH ARE REPRESENTED IN M
     1ODULES*,/,9X,*ONE MODULE = 40 INCHES*)
50    FORMAT (1H0,3(1H*),*THE LAND WIDTH EXCEEDED THE AVAILABLE PLOTTING
     1 WIDTH WHICH IS EQUAL TO 50 TIMES THE MODULE*)
      END
```

CD TOT   0253

```
      SUBROUTINE LOCATE (ID,JD,MX,MY,N,INTRMD,CLOSE,WIN,IWIN,LAY,LAYW,CG
     1,CGF,CD,IDRC1,IDRC2,LAYR,XNAME,UNAME)
      DIMENSION LAYW(67,67), LAY(67,67), IWIN(N), CLOSE(N,N), MX(N), WIN
     1(N), MY(N), CG(N), CD(N), CGF(N), IDRC1(N), IDRC2(N), LAYR(67,67),
     2 XNAME(N)
      COMPLEX CG,CGF
C     ******************************************************************
C
C     THIS SUBROUTINE WILL LOCATE ALL THE ROOMS IN THE LAYOUT MATRIX
C     USING THE CLOSENESS RATINGS BETWEEN THE DIFFERENT ROOMS AS WEIGHTS
C     TO DETERMINE THE OPTIMUM POSITION OF EACH ROOM RELATIVE TO THE OTH
C
C     ******************************************************************
C
C     SETTING ALL THE ELEMENTS OF THE LAYOUT MATRIX EQUAL TO ZERO
C     -----------------------------------------------------------
C
      DO 1 I=1,ID
      DO 1 J=1,JD
      LAY(I,J)=0
      LAYW(I,J)=0
      LAYR(I,J)=0
    1 CONTINUE
      DO 2 I=1,N
      IWIN(I)=IFIX(WIN(I))
    2 CONTINUE
C
C     STARTING THE GRAPH PLOTTING
C     ---------------------------
C
      YL=10.5
      XMARG=5.0
      YMARG=0.5
      SLASH=0.1
      XID=FLOAT(ID)
      XJD=FLOAT(JD)
      SCALE=(YL-YMARG)/XJD
      XL=SCALE*XID+XMARG
      CALL PLAN1 (XL,YL,XMARG,YMARG,XID,XJD,SCALE,SLASH,UNAME)
C
C     PLACE THE MOST IMPORTANT ROOM IN THE CENTER OF THE LAYOUT MATRIX
C     ----------------------------------------------------------------
C
      LP=1
      IP=IWIN(LP)
      IDP=(ID-MY(IP))/2
      IDP1=IDP+1
      IDP2=IDP+MY(IP)
      JDP=(JD-MX(IP))/2
      JDP1=JDP+1
      JDP2=JDP+MX(IP)
      DO 3 I=IDP1,IDP2
      DO 3 J=JDP1,JDP2
      LAY(I,J)=IP
      LAYW(I,J)=IP
    3 CONTINUE
      CX=(FLOAT(JDP1+JDP2))/2.0
      CY=(FLOAT(IDP1+IDP2))/2.0
      CG(LP)=CMPLX(CX,CY)
      CGF(LP)=CG(LP)
    4 CONTINUE
      DO 5 I=1,ID
      DO 5 J=1,JD
      IF (LAY(I,J).EQ.IP) GO TO 6
    5 CONTINUE
      WRITE (6,50) IP
      STOP 1
    6 RONAME=XNAME(IP)
      CALL PLAN2 (IDP1,IDP2,JDP1,JDP2,XMARG,YMARG,SCALE,RONAME,ID,JD)
      JDP11=JDP1-1
      IDP11=IDP1-1
      JDP21=JDP2+1
      IDP21=IDP2+1
      IG=IDRC1(IP)
      IGG=IDRC2(IP)
      IF(IDRC1(IP).EQ.0) GO TO 7
      IH=1
```

```
      GO TO (8,10,12,14), IG
7     IF(IDRC2(IP).EQ.0) GO TO 16
      IH=2
      GO TO (8,10,12,14), IGG
8     DO 9 I=1,IDP11
      DO 9 J=JDP1,JDP2
      LAY(I,J)=1000
9     CONTINUE
      GO TO (7,16), IH
10    DO 11 I=IDP1,IDP2
      DO 11 J=JDP21,JD
      LAY(I,J)=1000
11    CONTINUE
      GO TO (7,16), IH
12    DO 13 I=IDP21,ID
      DO 13 J=JDP1,JDP2
      LAY(I,J)=1000
13    CONTINUE
      GO TO (7,16), IH
14    DO 15 I=IDP1,IDP2
      DO 15 J=1,JDP11
      LAY(I,J)=1000
15    CONTINUE
      GO TO (7,16), IH
16    CONTINUE
C
C     PLACING THE NEXT WINNERS IN THE LAYOUT MATRIX
C     ---------------------------------------------
C
      DO 17 I=1,ID
      DO 17 J=1,JD
      LAYW(I,J)=LAY(I,J)
17    CONTINUE
      IF (LP.EQ.N) GO TO 44
      IF (INTRMD.EQ.1) GO TO 41
18    ICOUNT=0
      LP=LP+1
      IP=IWIN(LP)
      IG=IDRC1(IP)
      IGG=IDRC2(IP)
      SUMB=1.E+15
      MYY=MY(IP)-1
      MXX=MX(IP)-1
19    LL=ID-MYY
      MM=JD-MXX
      DO 40 I=1,LL
      L1=I+MYY
      DO 39 J=1,MM
      M1=J+MXX
      DO 20 L=I,L1
      DO 20 M=J,M1
      IF (LAYW(L,M).NE.0) GO TO 39
20    CONTINUE
      IF (IDRC1(IP).NE.0) GO TO 22
21    IF (IDRC2(IP).NE.0) GO TO 23
      GO TO 32
22    IH=1
      GO TO (24,26,28,30), IG
23    IH=2
      GO TO (24,26,28,30), IGG
24    I1=I-1
      DO 25 L=1,I1
      DO 25 M=J,M1
      IF (LAYW(L,M).EQ.0.OR.LAYW(L,M).EQ.1000) GO TO 25
      GO TO 39
25    CONTINUE
      GO TO (21,32), IH
26    M11=M1+1
      DO 27 L=I,L1
      DO 27 M=M11,JD
      IF (LAYW(L,M).EQ.0.OR.LAYW(L,M).EQ.1000) GO TO 27
      GO TO 39
27    CONTINUE
      GO TO (21,32), IH
28    L11=L1+1
```

```
      DO 29 L=L11,ID
      DO 29 M=J,M1
      IF (LAYW(L,M).EQ.0.OR.LAYW(L,M).EQ.1000) GO TO 29
      GO TO 39
29    CONTINUE
      GO TO (21,32), IH
30    J1=J-1
      DO 31 L=I,L1
      DO 31 M=1,J1
      IF (LAYW(L,M).EQ.0.OR.LAYW(L,M).EQ.1000) GO TO 31
      GO TO 39
31    CONTINUE
      GO TO (21,32), IH
32    CONTINUE
      DO 33 L=I,L1
      DO 33 M=J,M1
      LAYW(L,M)=IP
33    CONTINUE
      CX=FLOAT(J+M1)/2.0
      CY=FLOAT(I+L1)/2.0
      CG(LP)=CMPLX(CX,CY)
      LP1=LP-1
      SUMA=0.0
      DO 34 K=1,LP1
      IPP=IWIN(K)
      CD(K)=CABS(CGF(K)-CG(LP))
      SUMA=SUMA+CD(K)*CLOSE(IP,IPP)
34    CONTINUE
      IF (SUMA.GE.SUMB) GO TO 37
      SUMB=SUMA
      DO 35 II=1,ID
      DO 35 JJ=1,JD
      IF (LAY(II,JJ).EQ.IP) LAY(II,JJ)=0
35    CONTINUE
      DO 36 L=I,L1
      DO 36 M=J,M1
      LAY(L,M)=IP
      LAYW(L,M)=0
36    CONTINUE
      CGF(LP)=CG(LP)
      IDP1=I
      IDP2=L1
      JDP1=J
      JDP2=M1
      GO TO 39
37    CONTINUE
      DO 38 K=I,L1
      DO 38 KK=J,M1
      LAYW(K,KK)=0
38    CONTINUE
39    CONTINUE
40    CONTINUE
      IF (MXX.EQ.MYY) GO TO 4
      IF (ICOUNT.EQ.1) GO TO 4
      ICOUNT=1
      MXX=MY(IP)-1
      MYY=MX(IP)-1
      GO TO 19
41    WRITE (6,47) LP
      DO 42 I=1,ID
      DO 42 J=1,JD
      LAYR(I,J)=LAY(I,J)
      IF (LAYR(I,J).EQ.1000) LAYR(I,J)=0
42    CONTINUE
      DO 43 I=1,ID
      WRITE (6,48) (LAYR(I,J),J=1,JD)
43    CONTINUE
      GO TO 18
44    DO 45 I=1,ID
      DO 45 J=1,JD
      IF (LAY(I,J).EQ.1000) LAY(I,J)=0
45    CONTINUE
      WRITE (6,49)
      DO 46 I=1,ID
      WRITE (6,48) (LAY(I,J),J=1,JD)
```

```
46    CONTINUE
      WRITE (6,51) SUMB
      CALL PLAN3 (XL,YL,XMARG,YMARG,XID,XJD,SCALE,SLASH,UNAME)
      CALL PLOT (22.0,0.0,999)
      RETURN
C
C
47    FORMAT (1H1,* INTERMEDIATE PLAN LAYOUT        STAGE NO. *,I4,///)
48    FORMAT (1H0,/,45I3)
49    FORMAT (1H1,* FINAL PLAN LAYOUT *,///)
50    FORMAT (1H0,///,3(2H**),* THERE IS NO AVAILABLE SPACE TO LOCATE TH
     1E ROOM NO. *,I4,3(2H**),///)
51    FORMAT (1H0,///,2H**,* THE SCORE OF THIS LAYOUT IS = *,F12.4,//,2H
     1**,* NOTE  THE LESS THE SCORE THE BETTER THE LAYOUT*,/)
      END
```

CD TOT   0242

```
      SUBROUTINE RANK (N,TCR,PRIOR,TCR1)
      DIMENSION TCR(N), PRIOR(N), TCR1(N)
C
C     ******************************************************************
C     THIS SUBROUTINE DETERMINES THE PRIORITY FOR EACH ROOM ACCORDING
C     TO ITS TCR
C     ******************************************************************
C
      DO 1 I=1,N
      TCR1(I)=TCR(I)
1     CONTINUE
      DO 3 K=1,N
      II=1
      DO 2 I=2,N
      IF (TCR1(I).LE.TCR1(II)) GO TO 2
      II=I
2     CONTINUE
      PRIOR(K)=FLOAT(II)
      TCR(II)=TCR1(II)
      TCR1(II)=0.0
3     CONTINUE
      RETURN
      END
```

CD TOT 0023

```
      SUBROUTINE AMR (IK,N,CLOSE,L,WIN)
      DIMENSION CLOSE(N,N), WIN(N)
C
C     ******************************************************************
C     THIS SUBROUTINE FINDS THE MOST RELATED ROOMS TO THE FIRST WINNER
C     ******************************************************************
C
      II=1
      DO 1 I=2,N
      IF (CLOSE(IK,I).LE.CLOSE(IK,II)) GO TO 1
      II=I
1     CONTINUE
      L=L+1
      WIN(L)=FLOAT(II)
      IF(II.EQ.N) GO TO 3
      II1=II+1
      DO 2 K=II1,N
      IF (CLOSE(IK,K).NE.CLOSE(IK,II)) GO TO 2
      L=L+1
      WIN(L)=FLOAT(K)
2     CONTINUE
3     CONTINUE
      RETURN
      END
```

CD TOT 0024

```
      SUBROUTINE AMR2 (N,TOTAL,L,WIN,NR)
      DIMENSION TOTAL(N), WIN(N)
C
C     ****************************************************************
C     THIS SUBROUTINE FINDS THE MOST RELATED ROOMS TO THOSE PREVIOUSLY
C     SELECTED
C     ****************************************************************
C
      II=1
      DO 1 I=2,N
      IF (TOTAL(I).LE.TOTAL(II)) GO TO 1
      II=I
1     CONTINUE
      NR=1
      L=L+1
      WIN(L)=FLOAT(II)
      IF (II.EQ.N) GO TO 3
      II1=II+1
      DO 2 K=II1,N
      IF (TOTAL(K).NE.TOTAL(II)) GO TO 2
      NR=NR+1
      L=L+1
      WIN(L)=FLOAT(K)
2     CONTINUE
3     CONTINUE
      RETURN
      END
```

CD TOT 0027

```
      SUBROUTINE PLAN1 (XL,YL,XMARG,YMARG,XID,XJD,SCALE,SLASH,BCD)
C
C     ****************************************************************
C
C     THIS SUBROUTINE WILL SET THE ORIGIN  FOR THE PLOTTING,
C     WILL PLOT THE OUTER CONTOUR FOR THE LAYOUT AND WILL
C     DRAW SLASHES ON THE CONTOUR THE DISTANCE BETWEEN ANY TWO
C     CONSECUTIVE SLASHES BEING THE MODULE.
C
C     XMARG   IS THE MARGIN AT THE LEFT OF THE PLAN (FROM THE ORIGIN )
C     YMARG   IS THE MARGIN LEFT BELOW THE PLAN
C     XL      IS THE TOTAL WIDTH OF THE PLOT (INCLUDING THE MARGIN)
C     YL      IS THE TOTAL HEIGHT OF THE PLOT(INCLUDING THE MARGIN)
C     SCALE   IS THE SCALE OF THE DRAWING
C     SLASH   IS THE WIDTH OF THE SLASH
C
C     ****************************************************************
C
      CALL PLOT (0.0,0.0,-3)
      CALL DATE (D1)
      CALL LETTER (6,0.3,270.0,1.0,10.0,BCD)
      CALL LETTER (10,0.3,270.0,2.0,10.0,D1)
C
C     DRAW THE LAYOUT BORDERS
C     -----------------------
C
      CALL PLOT (XMARG,YMARG,3)
      CALL PLOT (XL,YMARG,2)
      CALL PLOT (XL,YL,1)
      CALL PLOT (XMARG,YL,1)
      CALL PLOT (XMARG,YMARG,1)
C
C     MARK THE MODULAR DISTANCES ON THE BORDERS
C     -----------------------------------------
C
      YSTEP=1.0*SCALE
      XOR=XMARG
      YOR=YMARG
 1    CONTINUE
      CALL PLOT (XOR-SLASH,YOR,3)
      CALL PLOT (XOR+SLASH,YOR,2)
      CALL PLOT (XL-SLASH,YOR,3)
      CALL PLOT (XL+SLASH,YOR,2)
      YOR=YOR+YSTEP
      IF (YOR.LE.YL) GO TO 1
      XSTEP=1.0*SCALE
 2    CONTINUE
      CALL PLOT (XOR,YMARG-SLASH,3)
      CALL PLOT (XOR,YMARG+SLASH,2)
      CALL PLOT (XOR,YL-SLASH,3)
      CALL PLOT (XOR,YL+SLASH,2)
      XOR=XOR+XSTEP
      IF (XOR.LE.XL) GO TO 2
      RETURN
      END
```

CD TOT   0055

```
      SUBROUTINE PLAN2 (IDP1,IDP2,JDP1,JDP2,XMARG,YMARG,SCALE,RONAME,ID,
     1JD)
C
C     ************************************************************
C
C     THIS SUBROUTINE WILL PLOT ONE ROOM IN ITS LOCATION AS DETERMINED
C     IN THE CALLING PROGRAM AND WILL WRITE ITS NAME AS GIVEN BY THE USE
C
C     ************************************************************
C
C
      X1=FLOAT(ID-IDP1+1)*SCALE+XMARG
      X2=X1
      X3=FLOAT(ID-IDP2)*SCALE+XMARG
      X4=X3
      Y1=FLOAT(JD-JDP1+1)*SCALE+YMARG
      Y4=Y1
      Y2=FLOAT(JD-JDP2)*SCALE+YMARG
      Y3=Y2
      XCG=(X1+X4)/2.0-.03
      YCG=(Y1+Y2)/2.0+.3
C
C     PLOT THE ROOM
C     -------------
C
      CALL PLOT (X1,Y1,3)
      CALL PLOT (X2,Y2,2)
      CALL PLOT (X3,Y3,1)
      CALL PLOT (X4,Y4,1)
      CALL PLOT (X1,Y1,1)
C
C     WRITE DOWN THE NAME OF THE ROOM
C     -------------------------------
C
      ENCODE (10,1,BCD) RONAME
      CALL LETTER (10,2,270.0,XCG,YCG,BCD)
      RETURN
C
    1 FORMAT (A10)
      END
```

CD TOT 0040

```
      SUBROUTINE PLAN3 (XL,YL,XMARG,YMARG,XID,XJD,SCALE,SLASH,BCD)
C
C     ******************************************************************
C
C     THIS SUBROUTINE WILL SET THE ORIGIN  FOR THE PLOTTING,
C     WILL PLOT THE OUTER CONTOUR FOR THE LAYOUT AND WILL
C     PREPARE A SHEET DIVIDED IN MODULAR UNITS
C
C     XMARG   IS THE MARGIN AT THE LEFT OF THE PLAN (FROM THE ORIGIN )
C     YMARG   IS THE MARGIN LEFT BELOW THE PLAN
C     XL      IS THE TOTAL WIDTH OF THE PLOT (INCLUDING THE MARGIN)
C     YL      IS THE TOTAL HEIGHT OF THE PLOT(INCLUDING THE MARGIN)
C     SCALE   IS THE SCALE OF THE DRAWING
C     SLASH   IS THE WIDTH OF THE SLASH
C
C     ******************************************************************
C
      XLLL=XL+3.0
      CALL PLOT (XLLL,0.0,-3)
      CALL DATE (D1)
      CALL LETTER (6,0.3,270.0,1.0,10.0,BCD)
      CALL LETTER (10,0.3,270.0,2.0,10.0,D1)
C
C     DRAW THE LAYOUT BORDERS
C     -----------------------
C
      CALL PLOT (XMARG,YMARG,3)
      CALL PLOT (XL,YMARG,2)
      CALL PLOT (XL,YL,1)
      CALL PLOT (XMARG,YL,1)
      CALL PLOT (XMARG,YMARG,1)
C
C     MARK THE MODULAR DISTANCES ON THE BORDERS
C     -----------------------------------------
C
      YSTEP=1.0*SCALE
      XOR=XMARG
      YOR=YMARG
1     CONTINUE
      CALL PLOT (XOR-SLASH,YOR,3)
      CALL PLOT (XL+SLASH,YOR,2)
      YOR=YOR+YSTEP
      IF (YOR.LE.YL) GO TO 1
      XSTEP=1.0*SCALE
2     CONTINUE
      CALL PLOT (XOR,YMARG-SLASH,3)
      CALL PLOT (XOR,YL+SLASH,2)
      XOR=XOR+XSTEP
      IF (XOR.LE.XL) GO TO 2
      RETURN
      END
```

CD TOT   0051