# MODULAR DESIGN IN BUILDINGS AND FURNISHINGS

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## PREFACE

A desire to work on a project that would involve a study of modular practice in the design world and the relationship of this theory to man and his environment has resulted in this exploration of modular design in buildings and furnishings. This has led to the discovery that architectural building systems, modular furnishings and industrial production can all be better coordinated by using a simple tool, a unit of measure called the "module."

Sincere gratitude is expressed to his major adviser, Mrs. Christine Salmon, Associate Professor in Housing and Interior Design, for her long-term, cordial guidance and indisputable patience; the completion of this study would not have been possible without her enthusiastic help, deliberate and constructive criticism and constant encouragement. Sincere thanks is given to other members of the Department of Housing and Interior Design, Dr. Florence McKinney, Dr. K. Kay Stewart, Miss Leevera Pepin, and Mr. Richard Berger, for their patient and constructive encouragement and assistance throughout my studies at Oklahoma State University.

The writer also extends indebtedness to his parents for their continuous encouragement and support.

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CHAPTER I

# INTRODUCTION

> The human body is a mass that resists the force of gravity, and consciousness of this fact causes me to interpret other masses according to his experience. Whenever a shape acquires a third dimension, it becomes a mass that is perceived as something to be lifted, pushed, or walked around; yet there are also fluid masses, which change shape constantly, such as clouds or ocean waves.[1]

Human dimensions are the basic premise, the primary design decision that one must be concerned about in order to design the environment for human needs. It is obvious that comfort will never be reached, nor fatigue be reduced, without a sound knowledge of body dimensions and measurements of the human figure. No matter what kind of environmental design, be it domestic, business or health facilities, continuing relationships to human measurements are of utmost importance.

Nothing is so permanent as man as the measure of design--past, present and future. He is the one constant factor among the ever increasing number of inventions with which he surrounds himself. It is impossible to correlate artistic and industrial efforts to help manufacture things of use, without gathering information about man first of all. If the information is to be worthwhile and useful, one of the things man must do is measure himself. It is this necessary concern of man with man, his functions and his furnishings which he wants to be comfortable and convenient and satisfying, that is the justification for study.

To know about man is to know a great deal about the possible environments in which he can function satisfactorily; the most successful environmental system would be an extension of his own system. To be a successful designer of products for a part, or the whole, of a human environment, a designer must have a complete understanding of the different types of human physique and be informed about the limitations of human performance. To achieve this in a world of mass produced machine production a unit of the measure of man is essential. Such a measure is called a "module."

The module or "modular" is a unit of measure based on the human body and on mathematics. It does not itself denote a specific size; however, it has been devised and used advantageously as criteria to establish standards. The human figure as the unit of measure in modular design relates the human being to buildings and products. One reason modular is used as the criterion to build things is to make them comfortable, convenient and easily arranged and re-arranged. It is also used to humanize machine produced environments.

This study will first explore some of the history of modular concepts as applied to classical buildings. The next set of observations will be directed toward the use of the module in structural building systems and lastly a study of contemporary furnishings known as "modular furniture." Because the module is a unit of measure based upon the human figure anthropometric measurements are an essential part of this study. Human dimensions, as defined by two standard texts are found in Appendix A.

The current trend of manufacturers to produce "modular furniture," which is becoming increasingly popular, was the first observation of this writer. In an attempt to discover the reason for this design phenomena the following observations have been made.

FOOTNOTES

[1]Marjorie Elliott Bevlin, Design Through Discovery (New York, 1970), p. 314.

# CHAPTER II

## HISTORICAL AND MATHEMATICAL DEVELOPMENTS

> The flower, the plant, the tree, the mountain, all these are upright, living in an environment. If the true greatness of their aspects draws attention to itself, it is because they seem contained in themselves, yet producing resonances all around. We stop short, conscious of so much natural harmony; and we look, moved by so much unity commanding so much space; and we measure what we see.[1]

With the advent of the Industrial Revolution, began a catalysmal transmutation of the world on human life; it instantaneously revealed the possibility of changing the whole world into a splendid and vibrant atmosphere because of the increased possibility of people's perceptual observance and sensitive imagination to their surroundings. Since then, the tranquil mind has frequently been shocked. Conscious touching and feeling of tangible or visual subjects has increased as well as perceptive imagination and contemplation related to this wondering globe and the sensitive searching for the mystery of the earth. Modern science and manufacturing processes are a part of this effort of problem solving.

Right after this drastic movement, the whole sphere was forced into a new epoch of social and economic change. In spite of perceived industrial advantages, nature continues to have an all pervading influence on man.

Le Corbusier said:

> Nature is ruled by mathematics, and the masterpieces of art in consonance with nature; they express the laws of nature and themselves proceed from those laws . . . . Music and architecture alike are a matter of measure.
>
> To take possession of space is the first gesture of the living, me and beast, plant and clouds, the fundamental manifestation of equilibrium and permanence. The first proof of existence is to occupy space.[2]

Thus it is suggested that the dimensioning of the human environment must come from measuring the body as the premise for all occupied space.

Studies of earlier buildings by scholars of many periods of history indicate that there is a consistent repetition of certain ratios or proportions for the size and spacing of the elements of the buildings. These studies substantiate the existence of a system or theory of proportion.

Vitruvius, a Roman architect and engineer, wrote of a system of proportion evolved from his study of Greek and Roman buildings. He explains his principles of symmetry and proportion and gives a detailed account of actual proportions of temples and the orders of architecture as follows:

> Proportion is a correspondence among the measures of an entire work, and of the whole to a certain part selected as standard. From this result the principles of symmetry. Without symmetry and proportion there can be no precise relation between its members as in the case of those of a well-shaped man . . . . Therefore, 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 (proportional) relations to the whole general scheme.[3]

Alberti (1404-1472), an Italian architect, painter, philosopher, musician, and author, has quoted Pythagoras from his basic concept of mathematics and music as follows:

> The numbers by means of which the agreement of sounds affects our ears with delight, are the very same which please our eyes and our minds . . . . We shall therefore borrow all our rules for harmonic relations from the musicians to whom this sort of numbers is extremely well known, and from those particular things wherein nature show herself most excellent and complete . . . . Alberti also stated that the architect who relies on these harmonies is not translating musical ratios into architecture but is making use of a universal harmony apparent in music.[4]

Both Vitruvius and Alberti implied the importance of the principle of repetition of ratios in architectural design. Barca, in Italy, and later Lloyd, in England, emphasized the importance of this principle rather than the indispensability of the relations themselves.

Jay Hambidge analyzed the Parthenon using mathematical systems of proportion (Figure 1). Wölfflin made similar analyses of Greek temples (Figure 2). The development of mathematics and various number series did not influence architectural thinking until the $\Phi$ (phi) series or "Fibonacci" series and its relationships to the "golden section" were noticed. The Fibonacci series 0, 1, 2, 3, 5, 8, 13, 21, . . . contains the ratio 1.618 as the numbers increase, which is the ratio of the golden section, 1:1.618.

Corbusier's theory of the "Modular" places a third square within two initial, adjoining squares, at the place called "the place of the right angle," (Figure 3 and Figure 4). The drawings in Figures 5 and 6 show this recapitulated by a man-with-arm-upraised, at the determining points of his occupation of space: space-foot, solar plexus, head, tips of fingers of the upraised arm-three. These intervals give rise to a series of two golden sections, one called the Red or Fibonacci

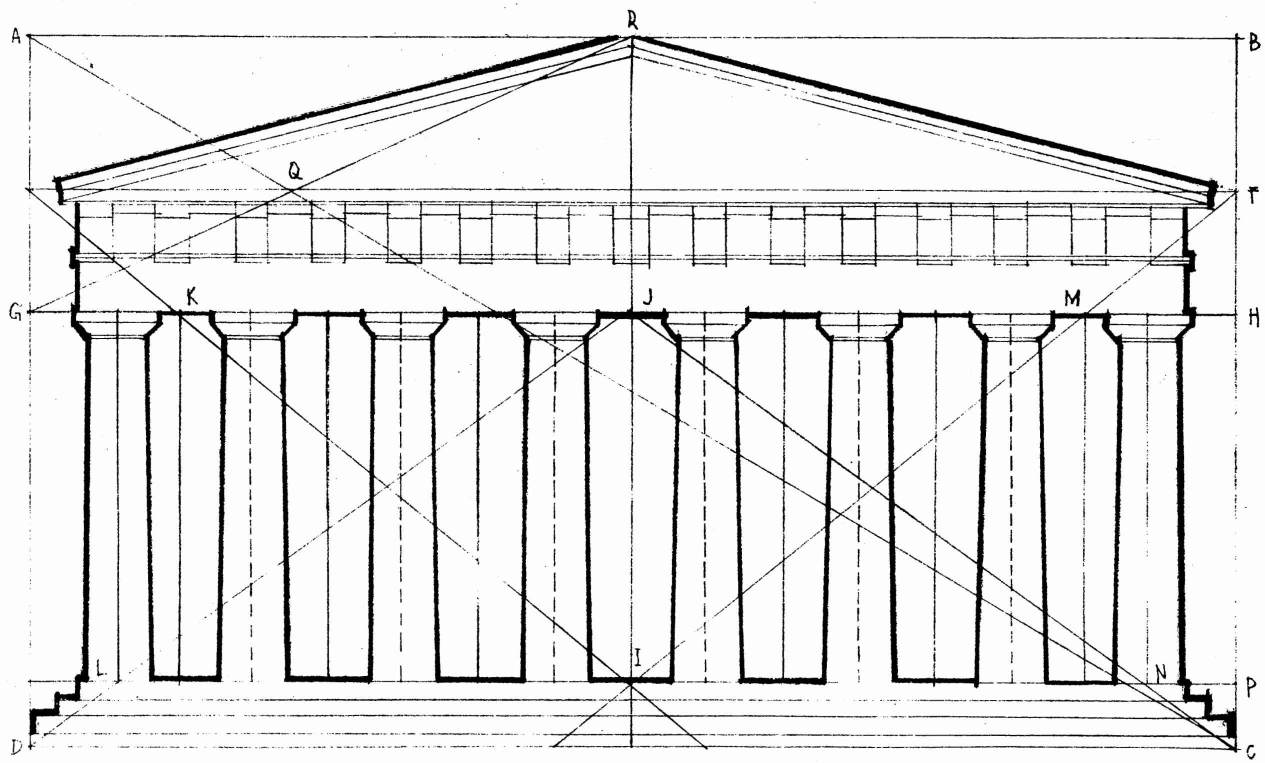



Figure 1. The Parthenon Temple

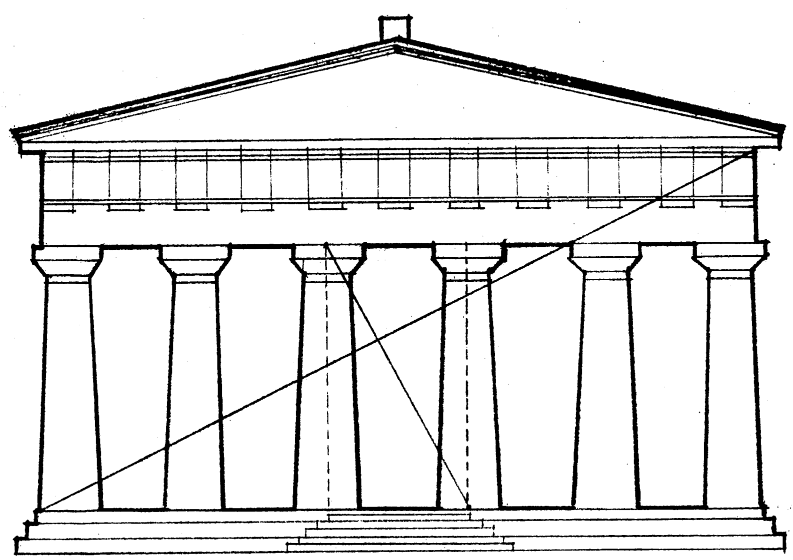


Figure 2. Zeustempel in Olympia

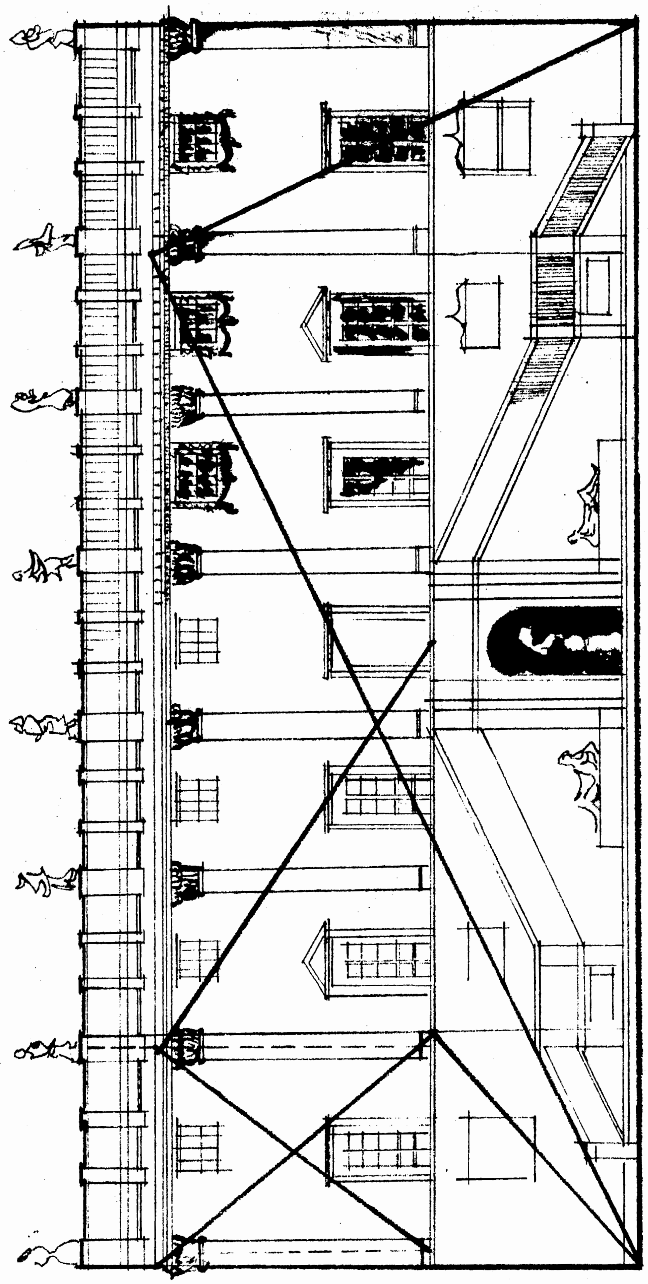


Figure 3. Capitol at Rome - Michelangelo

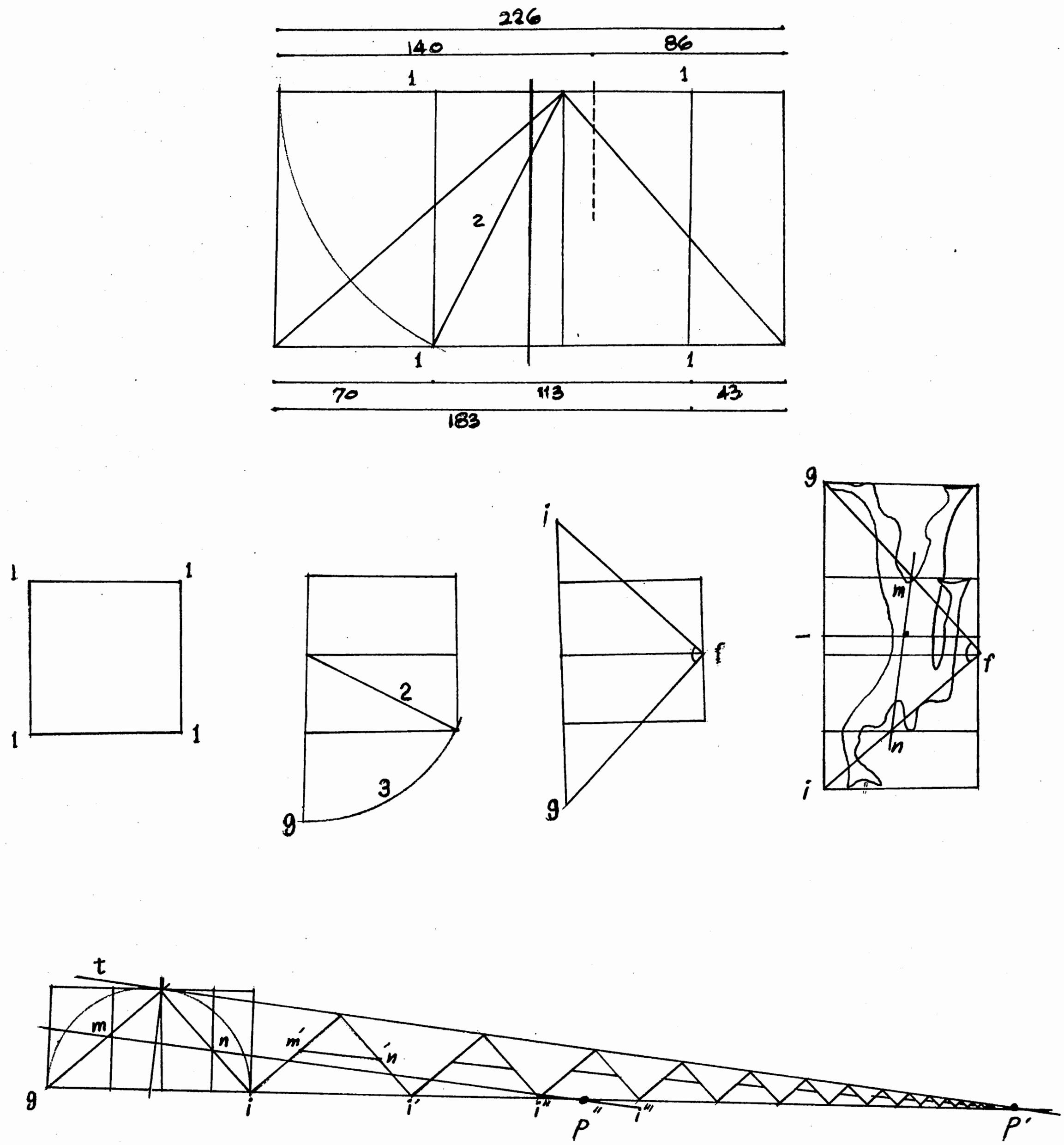



Figure 4. Original Concepts, to Insert in Two Contiguous Squares Containing a Man with Arms Upraised; a Third Square at "The Place of the Right Angle"

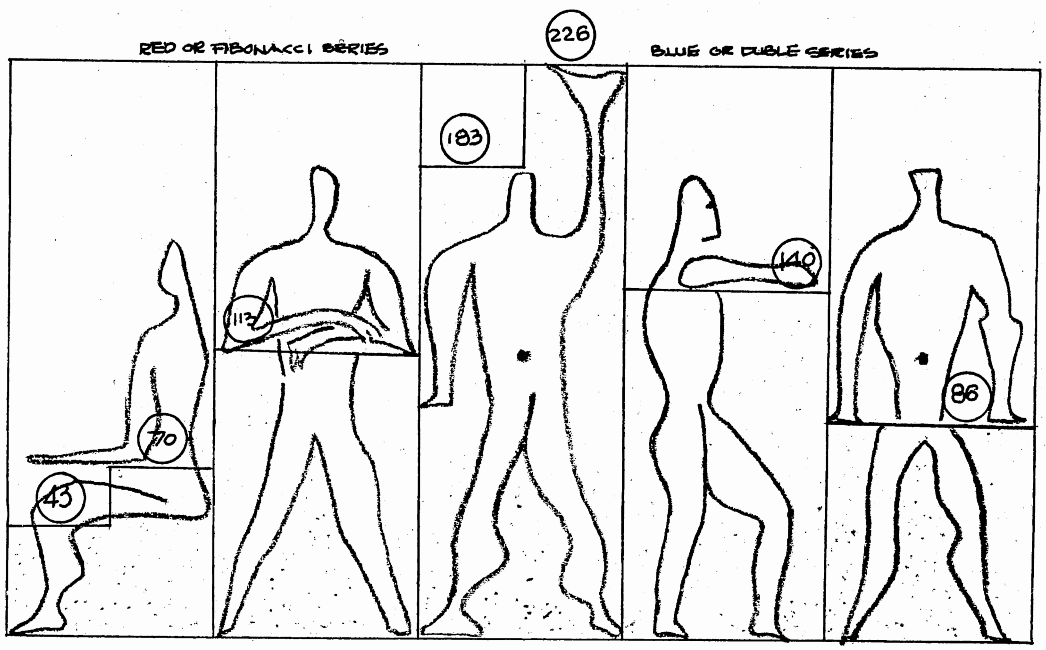



Figure 5. The Modular - Le Corbusier

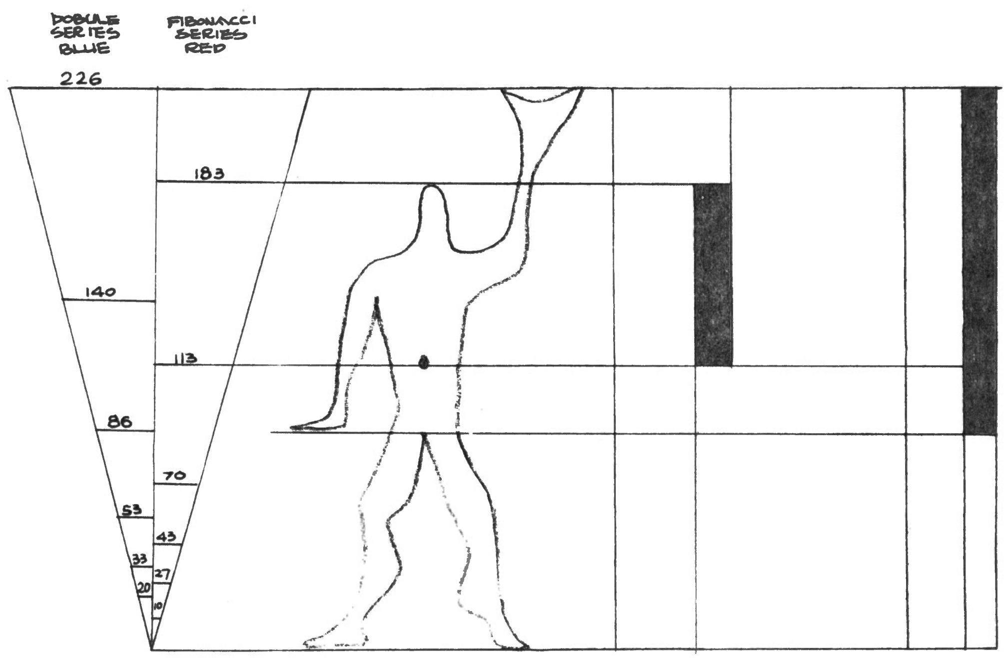



Figure 6. The Modular - Le Corbusier

series, the other called the Blue or double series.

Le Corbusier further states that mathematics offers the most powerful variation of a value: the single unit, the double unit, and the three golden sections. His drawings are described in principle as follows:

1. The Grid furnishes three measures: 113, 70, 43 (in centimeters), in a relation Ø (golden section); the Fibonacci series furnishes 43 + 70 = 113, or 113 - 70 = 43. Added together they give 113 + 70 = 183, 113 + 70 + 43 = 226.
2. These three measures (113 - 183 - 226) define the occupation of space by a man six feet in height.
3. The measure 113 furnishes the golden mean 70, which starts off a new series called the red series: 4-6-10-16-27-43-70-113-183-296, etc. . . . . The measure 226 (2 X 113) (the double unit) furnishes the golden mean 140-86, which starts off the second series, called the blue series: 13-20-33-53-86-140-226-366-592, . . . .
4. These values of measures can be described as characteristically related to the human stature.[5]

The modular concept, has been widely used and accepted by building contractors, architects, and product manufacturers. Its functions are economical, flexible, and plastic, and very efficient especially in the mass-production process. The modular concept, by providing interchangeable components, is capable of increasing production efficiency and inventiveness.

Modular practice now stands between a period of study and development and a period of greater acceptance and application. Research into modular techniques, production of modular materials, and adoption of modular practice by architectural offices must be part of the expansion process before the benefits of modular practice are realized.

Since module does not denote a size in terms of a common unit of measurement, its use when applied to coordination in building has led to some confusion. The basis for coordination must be an agreed upon common denominator for the sizes of building components in inches or centimeters. Manufacturers may advertise "modular" desks, cabinets, or other furnishings with repeated measurements, much like children's blocks or the pieces in the game of dominoes, but the products may not bear any dimensional relationship to the other components in a building. Modular furniture may have its own manufacturing standard without relation to the building in which it is placed. We need to coordinate the building module and the modular furniture manufacturing process.

> Having once set the standard building module, a uniform procedure may be laid down for any manufacturer to follow in order that the different components, when added together in the building, will have total modular dimensions. The procedure recognizes three facts: (1) that between all components there is a space or joint, (2) that the joint may vary from the 'best' size to a practical maximum or minimum, and (3) that the components may vary from the manufacturers' 'intended' size to a practical oversize or physical changes in the material during manufacture, expansion or contraction due to temperature or humidity or lack of precision manufacturing machinery.[6]

Architecture planning for the use of materials and components manufactured to meet modular-dimensional specifications is based on jointing and installation characteristics. This requires that in the design and sizing of a modular material the manufacturer must establish the limiting dimensions of the product and the workable tolerance of both product size and joint size. The guides to be followed are the basic concepts of modular coordination. Definitions and diagrams involved in modular practice include:

> Standard modular space grid. A reference space grid with planes spaced at the standard module of four inches.
>
> Standard modular component. A building component of standardized or specified dimensions which, when used with its joint, fits the standard modular space grid.

Manufacture dimension. A dimension of component which is the manufacturer's catalogue dimension. It may deviate within specified limits due to uncontrollable factors in manufacture. This dimension is set out on the drawing with the understanding that deviations will be taken up by the joint.

Standard modular dimension. (1) A dimension which used once or repeatedly is a multiple of the standard module of four inches; (2) the sum of a manufacture dimension and a joint.

Deviation. The difference between an actual dimension and the corresponding manufacture dimension. This difference may be positive, negative, or zero.

Limit dimensions. The maximum permitted oversize dimension (upper limit), or undersize dimension (lower limit), relative to the manufacture dimension.

Tolerance. The difference between the permitted oversize (upper limit) and the permitted undersize (lower limit).[7]

The standard modular space grid based on the four-inch module is illustrated in Figure 7, and the concepts in the definitions above are presented in graphic form in Figure 8.

The sizing of a modular component based on these definitions is governed by the standard modular space grid. The dimensions of the component are multiples of four inches, such as 8 by 8 by 16 inches, or fit a multiple of four inches when regularly repeated, such as 2 2/3 by 4 by 12 inches. This is not necessarily true of the thickness of a component.

The modular dimension of a component includes the size of the component and its joint. Therefore, the component size and joint size must be worked out together so that the sum does not exceed the modular dimension. After determining the desirable modular size for a component, the manufacturer establishes the desirable joint size and fizes the manufactured dimension. Next he studies the feasibility of maintaining the manufactured size during production of the component, ascertains the probable deviations, and

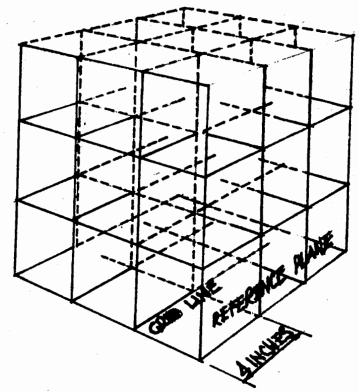



Figure 7. Standard Modular Space Grid
Based on Four Inch Module

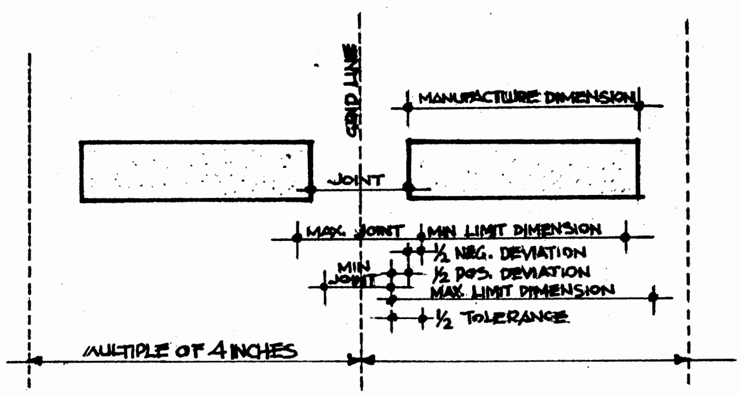



Figure 8. Basic Concepts of Sizing Components
for Modular Coordination

establishes the limits of deviation which are consistent with quality production. The allowable minimum and maximum joint limits are determined at this point because the joint will decrease as the manufactured dimension increases and will increase as the manufactured dimension decreases. This enables the over-all modular dimension to remain constant, as it must if there is to be no "creep" with relation to the modular space grid. The maximum and minimum sizes of the component itself must be such as not to narrow or widen the joint beyond practicable limits. These factors establish the limits of size within which the component must be manufactured, and the limits of joint size which may be used in construction.

One of the desirable goals of producing modular materials and components is the production of a minimum number of stock sizes which still allows the architect freedom in his solution of design requirements. Through careful study a minimum number of modular sizes can be coordinated to provide a wide range of flexibility. The coordination of sizes should include coordination with a wide range of other materials and components as well as with units of the same type, and should include compatibility with a variety of planning modules. Preferred sizes are a logical means of conversion to modular sizes and to a smaller inventory of sizes.

Aesthetic influences, such as various proportion theories are a manufacturing consideration, also to be considered are type of product and the manufacturing process.

As a matter of information, the problem of anyone claiming his products to be modular even when not in agreement with the four inch standard, has now been resolved by MBSA (Modular Building Standards Association) as Figure 9 shows the identifying symbol MODULAR, which is being incorporated into product literature for immediate recognition of truly modular products.[8]

This symbol applies to structural products that are manufactured by members of the Modular Building Standards Association. There are, however, many other structural building systems that employ modular concepts.

The progress which has been made in recent years in the conversion of several categories of building products to modular sizes is shown in Figure 10. Some are nearly 100 per cent modular, and there are no major categories of building materials in which modular products are not available.[9]

Figure 9. Identifying Symbol of Modular Building Standards Association

| Year | | Estimated Percentage of Modular Production |
|---|---|---|
| 1946-1950 | Concrete masonry units (brick, block, decorative, and miscellaneous) | 99 |
| 1948-1961 | Windows (wood, steel, aluminum) | 65 |
| 1961 | Steel doors | 5 |
| 1948-1960 | Clay masonry units (brick, structural tile, glazed tile, miscellaneous) | 50 |
| 1950-1960 | Rolled sheet siding and roofing materials (steel, aluminum, plastic) | 95 |
| 1950-1960 | Precast structural units (floor, decking, etc.) | 95 |
| 1950-1960 | Movable partitions | 75 |
| 1950-1960 | Ceiling materials (including integrated lighting and mechanical fixtures) | 95 |
| 1950-1960 | Miscellaneous items (access doors, fireplace hardware, flue lines, window-wall system, glass block, etc.) | 5-100 |

Figure 10. Progress of Conversion of Building Products to Modular Sizes

FOOTNOTES

[1]Le Corbusier, "A Harmonious Measure to the Human Scale Universally Applicable to Architecture and Mechanics," The Modular (Cambridge, 1954), p. 31.

[2]Ibid., pp. 29-30.

[3]Robert P. Darlington, Melvin W. Isenberg and David A. Pierce, Modular Practice (New York and London, 1962), p. 187.

[4]Ibid., pp. 188-189.

[5]Le Corbusier, p. 65.

[6]Darlington, p. 158.

[7]Ibid., pp. 145-146.

[8]The Current Status of Modular Coordination, Building Research Institute Publication 782 (Washington, D.C., 1960), p. 21.

[9]Darlington, p. 147.

# CHAPTER III

## STRUCTURAL BUILDING SYSTEMS

> The understanding of space and its effective use has a great deal to do with successful design. Positive and negative space are combined to create a piece of sculpture--the positive space forms the mass and the negative space flows around and through it. It is the space that remains within a ceramic pot or a silver bowl that determines its capacity and its use. The importance of space in architecture becomes clear if one conceives of space as being unlimited until the architect circumscribes it by erecting walls. The quality of the designed space determines the success of a building. It is only after the space is determined that the material, surface color, and texture of the walls are considered . . . . To know a building thoroughly one must take time to walk through it, allowing his spirit to flow through the space, over and around the divisions or walls, and out through the doors and windows. Anyone who has learned to 'feel' a building in all its possibilities can sense almost endless dimensions in its relationship to the human spirit.[1]

The concept of environment exceeds the limits of physical space, and therefore design should take into consideration the totality of relations between man and space. Space is regarded as the sum of physical dimensions and the equipment included within those dimensions. Space should be regarded as dynamically organized.[2]

Each element must be planned to be contained within the walls, floor, and ceiling of the unit. Because all parts always relate to the whole in environmental design, all objects have an affiliation with each other and with the surrounding space. As the eminent twentieth-century architect Eero Saarinen stated:

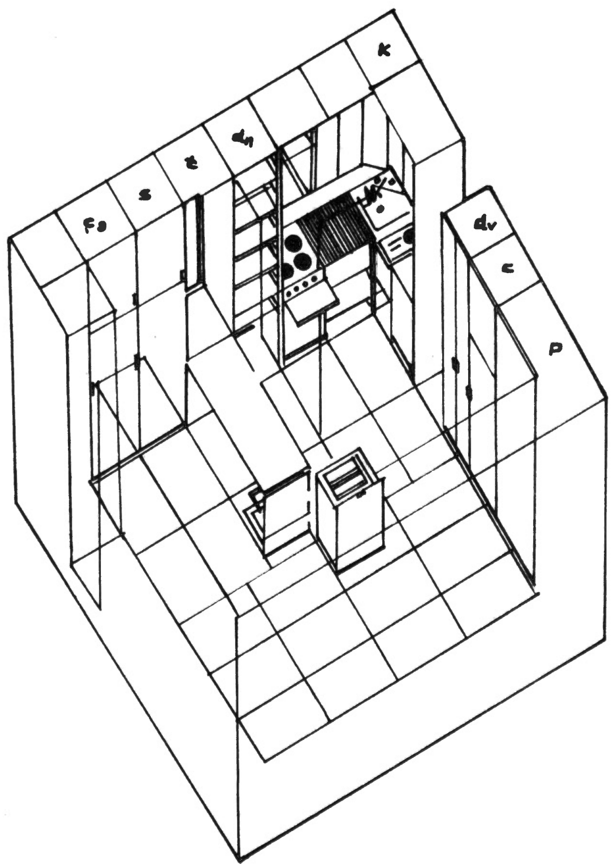
> Every object, small or large, has a relationship to its neighbor . . . . If the problem is an ashtray, then the way it relates to a table will influence its design. If the problem is a chair, then its solution must be found in the way it relates to the room cube. If it is a building, the townscape will affect the solution.[3]

The furnishings and accessory equipment in a room or a building are always playing a role in the relationship between the building and its surroundings. This implies the importance of designing norms for relationships.

In the manufacturing of goods and accessories, efficient industry demands standards to produce these interrelationships. Standards which can be widely accepted and practically applied to many aspects of production and coordinating of elements dictate the use of a module.

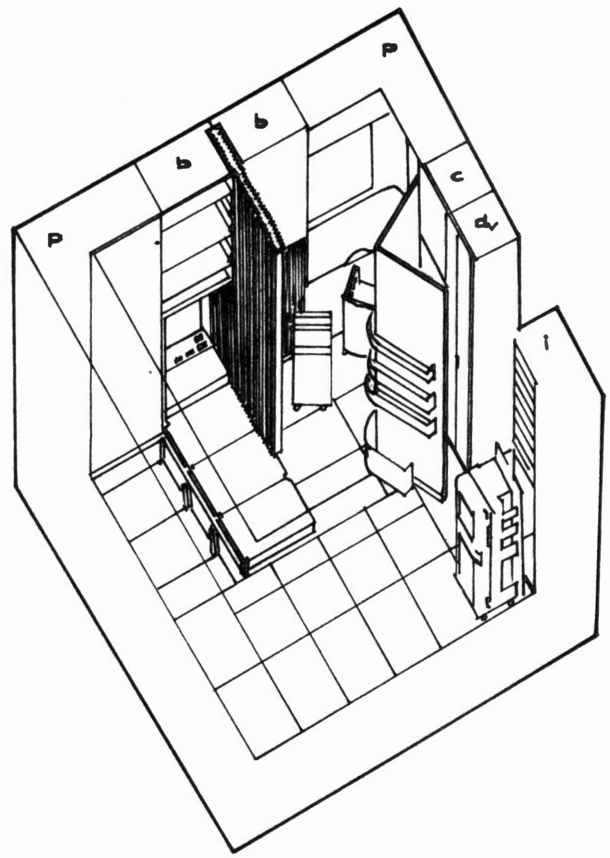
A project of modular housing planning by Italian architect Gianantonial Mari (Figures 11-A, 11-B, 11-C, 11-D) consisted of all modular equipment and furnishings within vertical extensions. This allowed for coordination with standard environments, and other dimensions of the habitat units of which this is the prototype. His design project was based on the following axioms:

1. The nonsense of designing a piece of equipment or a product that is not an instrument for the total solution of the habitat unit (i.e., avoiding designing objects limited to furnishing a space).
2. The necessity of being able to participate in the technical and structural decisions regarding buildings themselves, by offering design products that can be modularly multiplied and assembled according to precise systems, the purpose being to develop (starting at a basic typological, microurbanistic level) a different townscape, more consistent with the dynamism of modern-day development.
3. Scaling for execution, basing the project on actual structures and techniques of construction that can be carried out by modern industrial systems (hence taking into consideration criteria related to economics and production). This might allow a partial and gradual



A

Figure 11. A Project of Modular Housing Planning




B

Figure 11. Continued

C

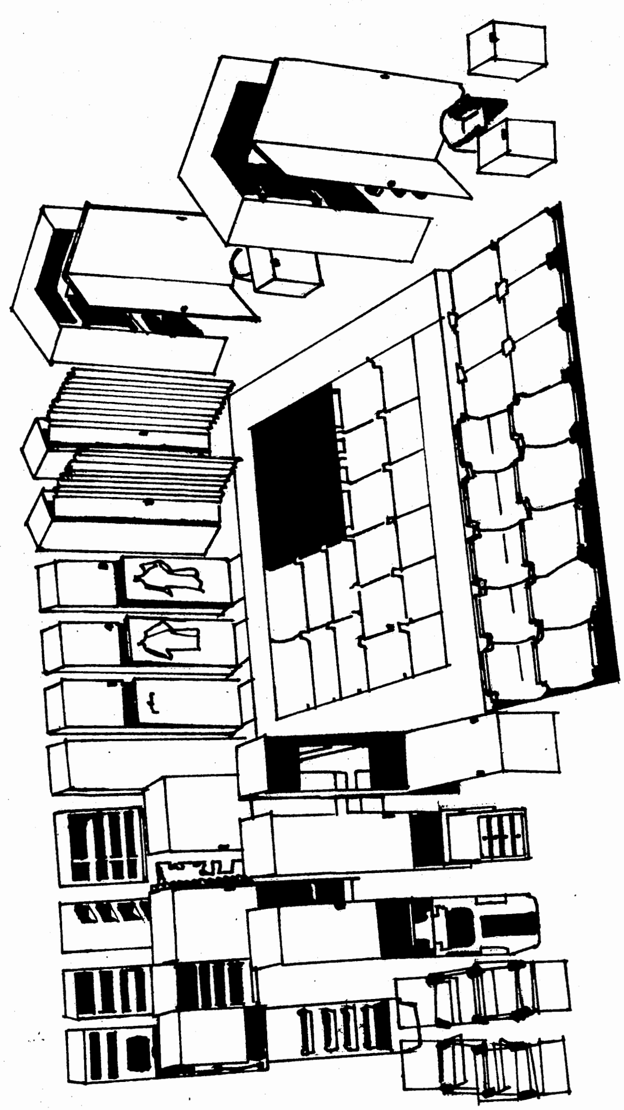
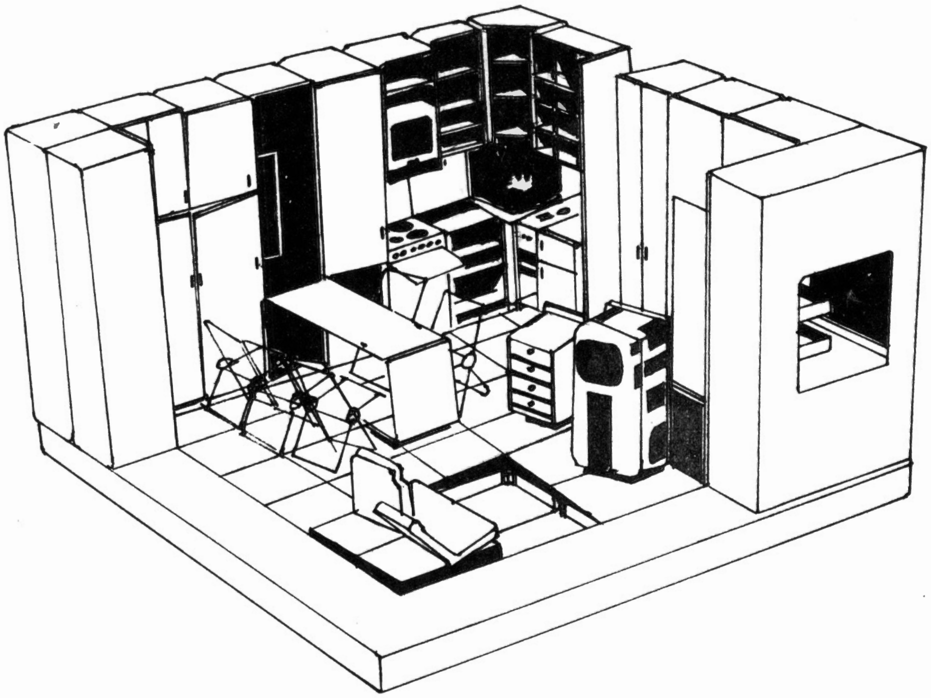


Figure 11. Continued



D

Figure 11. Continued

application of the design, as well as one that could be used immediately in collateral branches of building, such as trailers, houseboats, small prefabricated habitats (cottages), as well as motels, tourist colonies, and even temporary quarters for migratory workers.

4. The requirement, derived from the scaling, of a design that would permit rational, modern, and therefore economically valid mass production; this meant that all the equipment must be completely modular, enabling simplification in assembling and installation, so that the unit can be constructed and completed in the shortest possible time.[4]

The designers decided to adopt in their project the principle of designing all the equipment as completely modular and combinable units, which, together with a simple grill-support structure, are totally repeatable and can be used for structures of larger size by adapting the module, practically without any limitation of dimensions. The units constitute elements of separation from the outside environment, while, within, they provide the equipment that allows interaction of the functions of living.

Industrialization of housing, using more and larger prefinished and prefabricated components, appears essential to help offset the rising costs of land, labor and materials. Off-site fabrication permits maximum utilization of labor and materials under factory-controlled conditions with little loss in on-site time due to bad weather. Efficiency may be increased with the use of power tools and machinery and volume purchasing of materials and stockpiling of finished parts is possible. Greater convenience for workmen and better protection for finished materials is provided and site erection of components usually can be accomplished more economically and in less time by semiskilled or unskilled labor.

To save costs, mechanical components have been developed that combine furnace, air conditioner, water heater and electric power panel into one package. Larger mechanical components include completely furnished kitchens and bathrooms. The concept of prefinishing rooms has been extended to prefabricating up to half a house so that upon setting and joining two halves, an entire house is completed. Future developments may include assembling the entire unit and finishing it prior to site placement.[5]

The precast architectural concrete panel field has grown rapidly in the last decade. While precast architectural concrete units or sections are really not new to the architectural, engineering, and construction industries, their use has never enjoyed such a wide acceptance as now.

The nature and the content of a building system can be described from three different points of view: organizational structure, technical structure and planning. The organizational structure is composed of the following parts: the actual system, described by means of component catalogue, codification table, price list of components and assembly instructions, production organization, warehousing and sales organization, assembly organization, planning and development organization. From the technical standpoint a building system is composed of the following components: window, outside door, interior wall, door, framing, foundation, ceiling, roof, stairway and entire components (Figure 12). From the planning aspect, a building system is made up of the modular system.

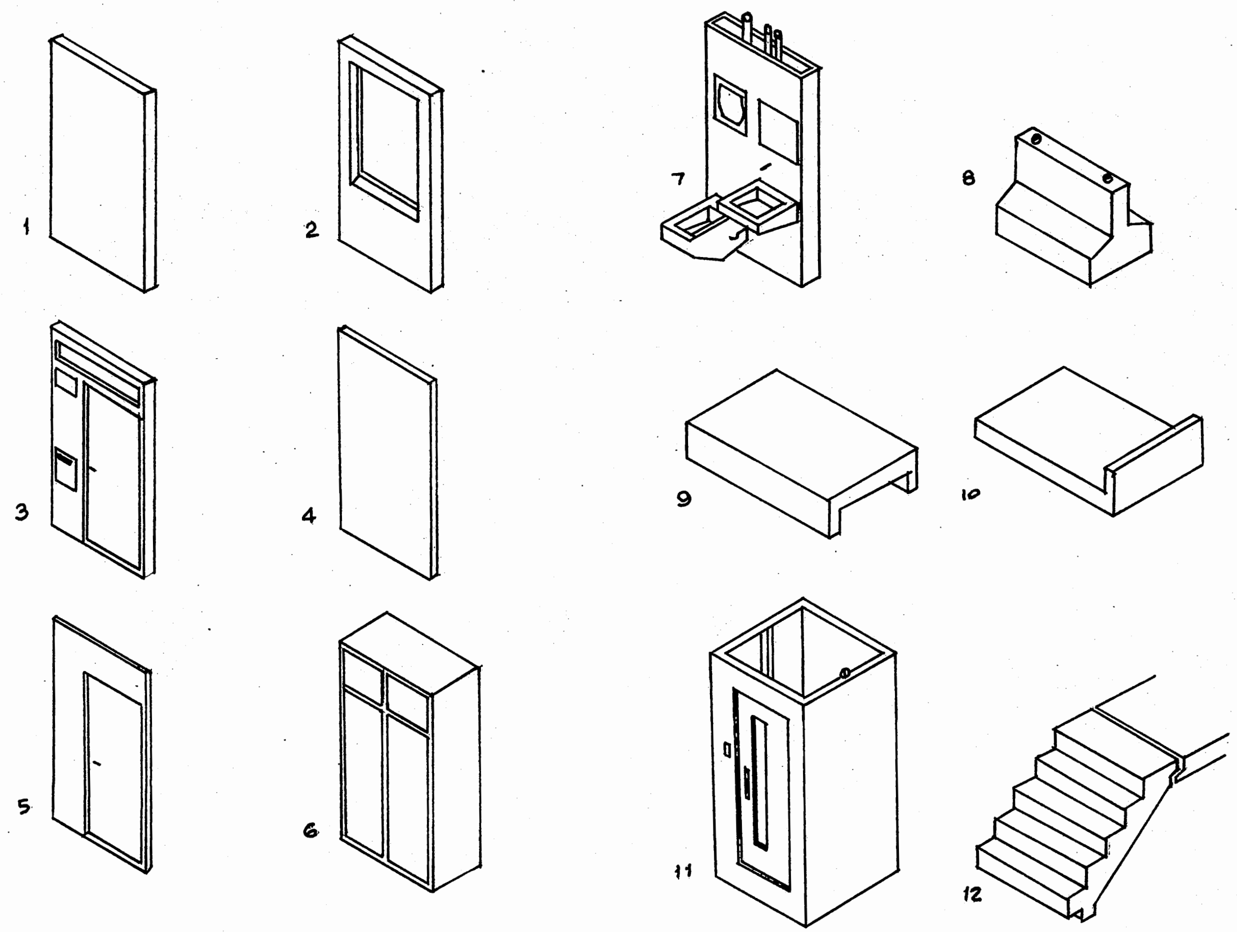



Figure 12. Components of a Building System

The organizational structure ensures steady production and gives the client a guarantee that he can obtain the desired building components at any time without long-term ordering. The technical structure guarantees the flawless functioning of the system and that all components correspond, that assembly can proceed without complications and that the climatic requirements are met. The planning structure guarantees that the architect's plans are in accord with the system. It also ensures that elements manufactured by different producers fit together.

This is known as component building (Figure 13-A). Component building can be achieved only if the following conditions obtain: the jointing and packing techniques are highly developed, building components of the most diverse origins can be jointed together, all components relate to a common module, and all parts fit together.

Whereas jointing techniques are a technical problem for the builder, as is also the case with traditional building methods, the modular system is a novel factor which controls the construction process on the basis of a mathematical ordering principle. The prescriptions and directives regulating the process are called setting of norms (or normalization) and standardization. Side by side with the systems, the functional structure or systems-built edifice is also subject to a developing process. Programmed instruction and the use of audio-visual teaching aids impose increased possibilities in building. This is called permutability, and the planning procedure that aims at flexibility is known as the open plan (Figure 13-B).[6]

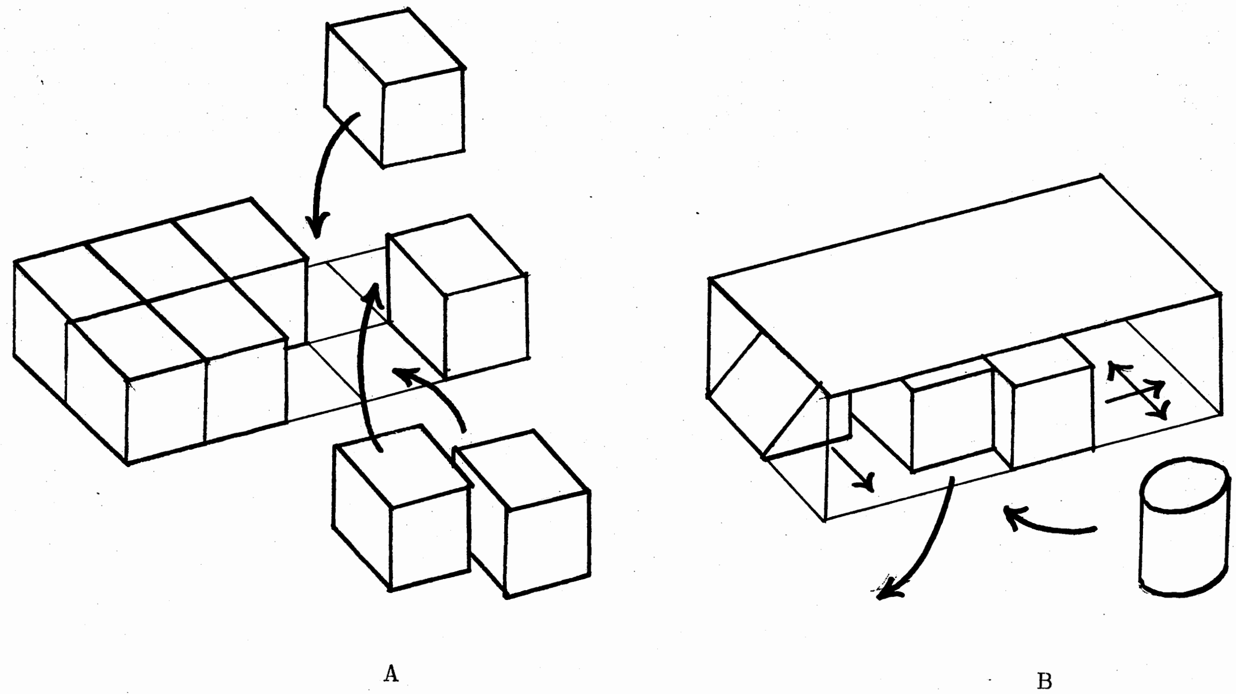



Figure 13. Building with Components (A) and The Open Plan (B)

The setting of norms (normalization) prescribes the properties and the quality required of building components. Most industrialized countries make use of such norms. In the case of standardization, we have prescribed dimensions which are employed for the production of building components (standardized windows, doors, ceiling panels, general measures, while the modules are exact sizes which both prescribe the dimensions of building components vary precisely, and indicate their position in the system.[7]

The basic tool used by the architect in the development and expression of a coordinated modular design is the grid, which is defined as "a grating or gridiron, or something resembling or likened to one."[8] However, in architecture usage a grid is a network of lines, running both horizontally and vertically, from which the measurements and the positions of building components may be determined. Several types of grids, each with a specific function, may be used in the design and coordination of a building. Successful use of the modular system requires the coordination of these grids. Each grid type should be considered as a tool to aid, not to dictate, the development of a design solution.

The planning grid, sometimes called the "design grid," is the basic means of achieving a logical and controlled plan solution. It is a repetitive shape developed from a basic functional requirement of a plan and is used for the general layout of the major rooms and other spaces in a building. As the planning of a school building, not all the required areas can be based easily on the same planning grid. A specific functional area such as a high-school drafting room could be developed from a planning grid based on the space requirements of a draftsman: size of drafting table, stool, reference area, aisle space, and storage. This planning grid would probably be different in size, shape, and dimensions from the grid used to lay out a classroom or other teaching space, which might be based on the total area required per student. However, if the dimensions of the various planning grids are multiples of the basic four inch module, the modular approach is established early in the design phase. A planning grid superimposed on a portion of the floor plan of an existing building is shown in Figure 14. This illustration is used only to show the concept of the planning grid as applied to the arrangement of interior office space; therefore no dimensions are given.[9]

The reference grid is developed specifically for use on the working drawings as an additional means of communication between the architect, his associates, the engineers and the contractor to locate and identify areas and details in the building. Frequently it is drawn as a light grid over the whole plan with letter and number coordinates similar to those on a map. The reference grid is shown only around the outside of a plan, or above or below an elevation, when the additional lines of the grid running through a drawing might cause confusion. In a modular project, the reference grid is a multiple of four inches and is usually a regular subdivision of the structural grid.[10]

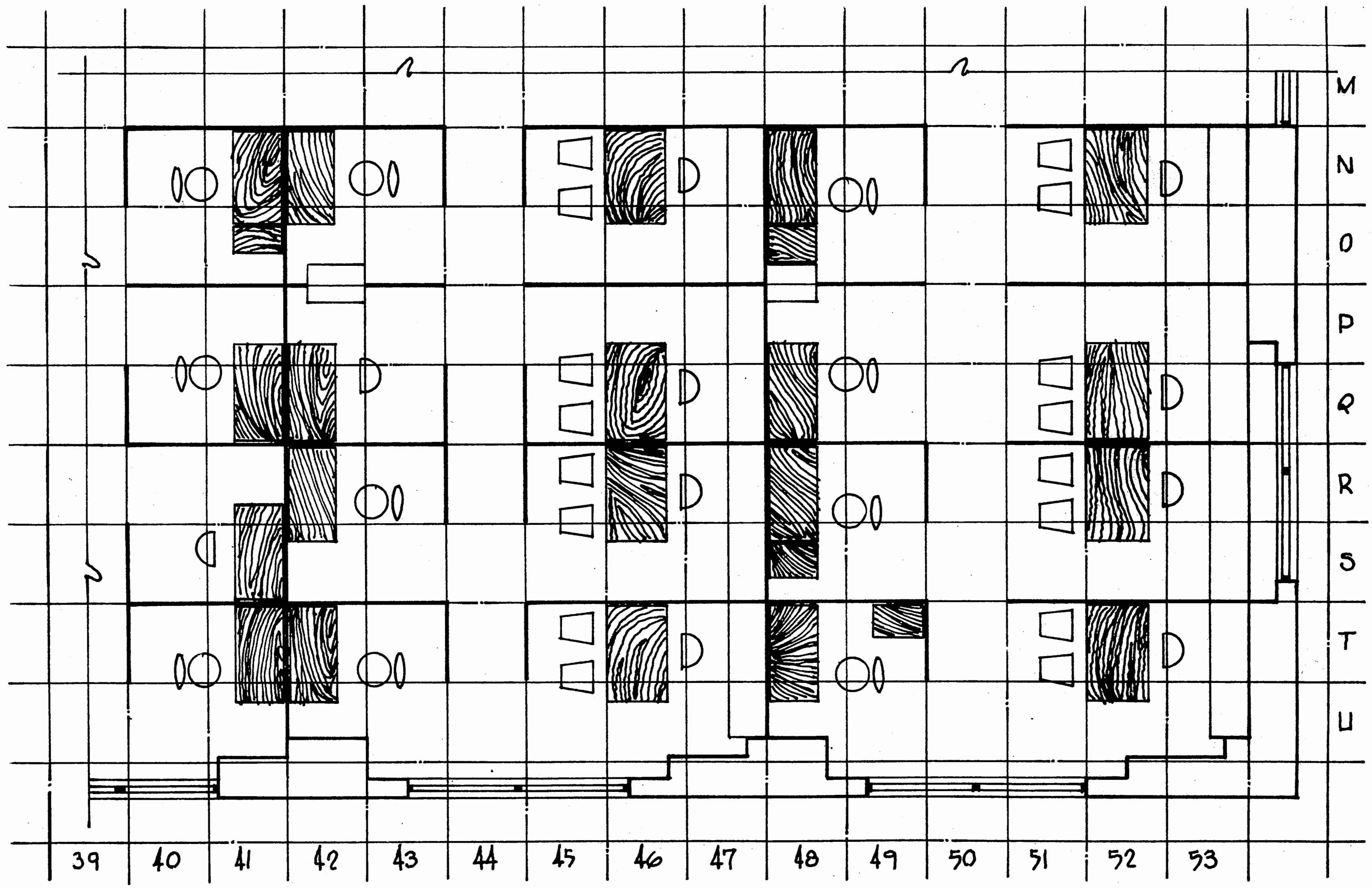



Figure 14. Planning Grid in Existing Building

The modular grid is used to complete the detailed coordination of a design by coordinating the building materials and correlating all the dimensions. Maximum coordination is obtained by means of the four-inch module because the majority of modular materials are sized according to this standard. Figure 15 illustrates modular bricks on a four-inch grid.

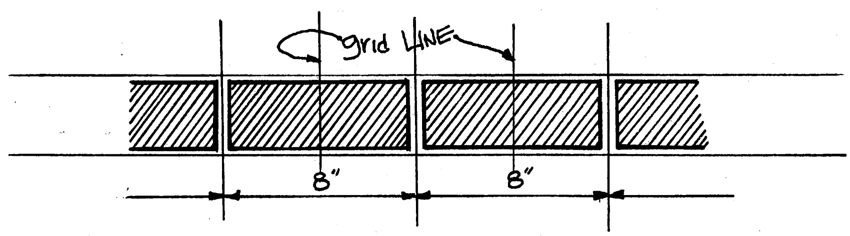



Figure 15. Modular Bricks on Four-Inch Grid

The four-inch module is visualized in use of a three dimensional grid occuring throughout a building. The building's structural and enclosing elements--columns, walls, partitions, beams, slab floors, ceilings, doors, windows--are related dimensionally to this grid, and the coordination of materials and components is expressed through reference to it.[11]

Depending on their functions, we speak of material module, production module, transport and assembly module, sanitary module and fitting module. The material module selected is influenced by factors arising from the choice of building materials. A drawn steel support, for example, will have quite different dimensions from a pressed asbestos-cement slab or a poured concrete panel. The cross section of the steel support ranges from 10 X 10 to 20 X 20 cm (1M X 1M), whereas the dimensions of the pressed asbestos-cement slab are around 1.20m X 2.40m (12M X 24 M). A reinforced concrete panel can easily be poured in sizes 3.00 to 4.50 X 2.40m (30M to 45M X 24M). The values to be selected must accordingly be in line with the most favorable dimensions of the building materials employed (Figure 16).[12]

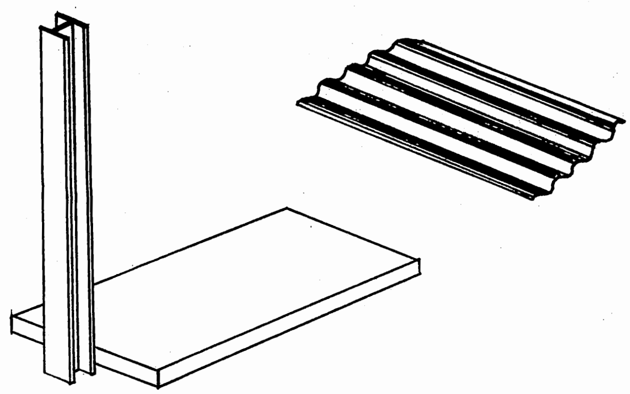


Figure 16. Material Module

The material module selected is influenced by factors arising from the production process of a building component. The strap press for aluminum profiles turns out products which measure only a few centimeters in one direction but products which in the longitudinal direction can be almost indefinitely long. The conveyor-system of a concrete components factory, on the other hand, can produce slabs which may measure up to 4.00 M in two directions. These limitations on dimensions have to be taken into account when the module to be assigned to a system is being determined, that is to say, the production module must be integrated in the modular numerical system.

The transport and assembly module takes into account factors arising from transport and assembly, width of roads and clearance on the component dimensions as regards transport.

The sanitary module includes siting and the type of sanitary equipment in a building. A well-conceived building system contains special sanitary elements, in which all ducts, installations and impermeable insulation are incorporated. The type and the size of the ducts and installations yield certain optimum measurements which are fixed by the values of the sanitary module.

In the same way built-in fittings like lockers, bookshelves, movable partitions, sliding doors and folding doors determine the fitting module, which again has to be integrated in the system module (Figure 17).[13]

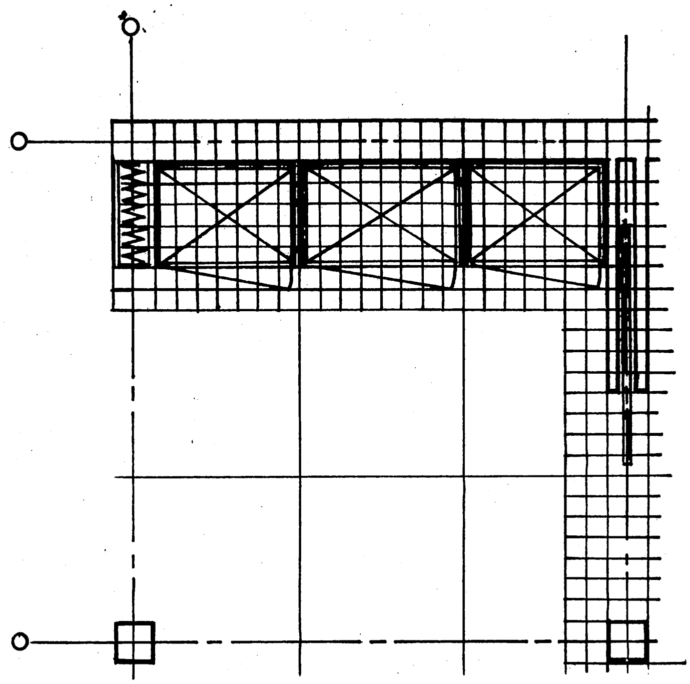


Figure 17. Fitting Module

The series of subsidiary modules can be extended as required, depending on the nature of the given building and system. Appropriate modules can also be elaborated for heating systems, lighting and ventilation equipment.

The basic module determines the series--the planning module, the value for the elaboration of the system and the architect's design. The structural module lays down the value of the static structure. In systems where space-dividing and supporting functions coincide, planning module and structural module are identical. In the case of skeletal frame systems, on the other hand, where static skeleton and partitioning elements constitute two different sub-stems, there is also a separate structural module, which relates to the supporting properties of selected building material.[14]

Every system does not display the same degree of flexibility. Some give the architect a great deal of freedom, others place considerable restrictions on him. The degree of flexibility depends on whether junction points and corners are developed for attachments in all directions, and how many stories a system is restricted to

1. A system which can expand in only one direction is known as a linear system.
2. A system which can develop in two directions is called two-dimensional.
3. A system with possibilities in all three directions is called three-dimensional (Figure 18).[15]

Structural Building Systems are many and varied. When based upon modular design they become flexible, interrelated components of a whole, and capable of accommodating modular furnishings.

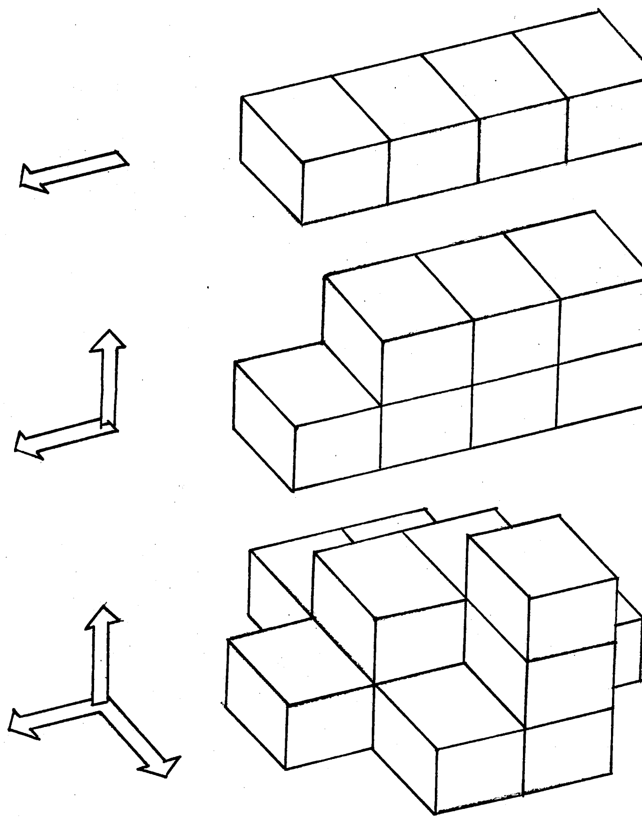


Figure 18. Linear and Multi-Dimensionsl Systems

## FOOTNOTES

[1]Marjorie Elliott Bevlin, Design Through Discovery (New York, 1970), pp. 293-294.

[2]Emilio Ambasz, ed., Italy: The New Domestic Landscape (Greenwich, 1972), p. 270.

[3]Bevlin, p. 37.

[4]Ambasz, p. 271.

[5]John L. Schmidt, Harold Bennett Olin and Walter H. Lewis, "Methods and Systems," Construction: Principles, Materials and Methods, 2nd Ed. (Chicago, 1972), p. 304.

[6]Thomas Schmid and Carlo Testa, Systems Building: An International Survey of Methods (New York, 1969), p. 40.

[7]Ibid., p. 42.

[8]Webster's New World Dictionary of the American Language (New York, 1957), p. 632.

[9]Robert P. Darlington, Melvin W. Isenberg and David A. Pierce, eds., Modular Practice (New York, 1962), p. 2.

[10]Ibid., pp. 2-7.

[11]Ibid., p. 7.

[12]Schmid and Testa, p. 52.

[13]Ibid., pp. 52-54.

[14]Ibid., p. 54.

[15]Ibid., pp. 58-60.

## CHAPTER IV

## MODULAR CONCEPTS OF FURNISHINGS

> Architecture and interior design (furnishings) are not only closely related; they actually perform the same function. Together they represent the culmination of the creative effort that attempts to compose a beautiful space.[1]

Because design ideas and skills are influenced by new materials, inventions and creativeness, design trends always have innovative features. Not only does architecture progress in this way but furnishings are continuously innovative. Relationships between architecture and furnishings, between the exterior and interior parts of a building, must be a balanced whole, each compatible with the other and together form an environment for maximizing human life, human comfort and delight.

Observing the furnishings of today, it is apparent that the modular concept is evident in the products of trend setting manufacturers. This reflects the fact that interior furnishings develop from architectural shapes and spaces, from structural building systems. This relatedness is essential in order to achieve an integrated, harmonious environment, otherwise the outcome is incompatible, like putting a quart into a pint pot.

Modular furnishings have developed from modular structural building systems. The nature and content of a building system is derived from three different components: organizational structure, technical structure and planning structure. In addition, components, connectors and packing become parts of modular design. Furniture constructed in this context is known as modular furniture.

From the standpoint of organizational structure Figure 19 illustrates a system designed for hospital facilities by Herman Miller Co. It is a system of containers, frames, carts and rails that coordinate the architectural and service functions of a hospital allowing easy exchange of linens and supplies. Programmed lockers delivered to nursing units transfer onto wall rails and free the cart to remove the exchange locker. Smaller carts and containers dispense supplies at the bedside.

From the standpoint of technical structure Figure 20 shows components, connectors and supports for packing. It is an integrated panel system totally compatible with all components. This system is designed by Tiffany Industries, Inc. This series of systems for office equipment and furniture has been produced and continuously researched and is a pace setter in this field. It is very flexible in assembling with hidden connectors and supports. The modular components fit together to provide versatility for the worker. It can be moved and interchanged with all parts of the system and its flexibility saves money and motivates people. Technical aspects make possible some of the planning aspects of modular design (Figure 21).

From the planning aspect, the modular furniture capabilities have increased because of new chemical substances such as foam, urethane, polyurethane foam and other new products. Consumers appreciate the integrity of these new materials as evidenced by their popular acceptance; besides, these materials give manufacturers more

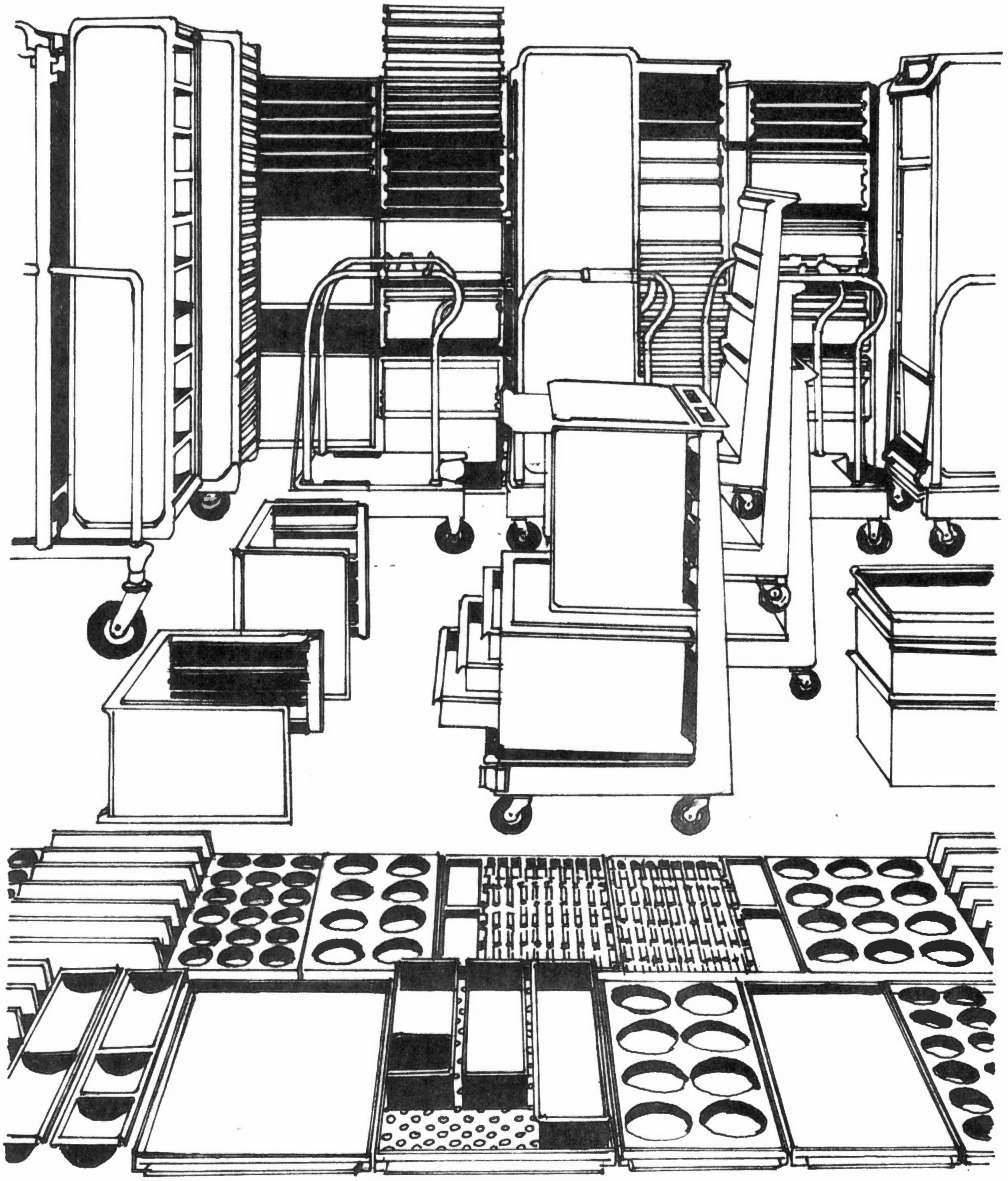


Figure 19. Organizational Structure Showing Components

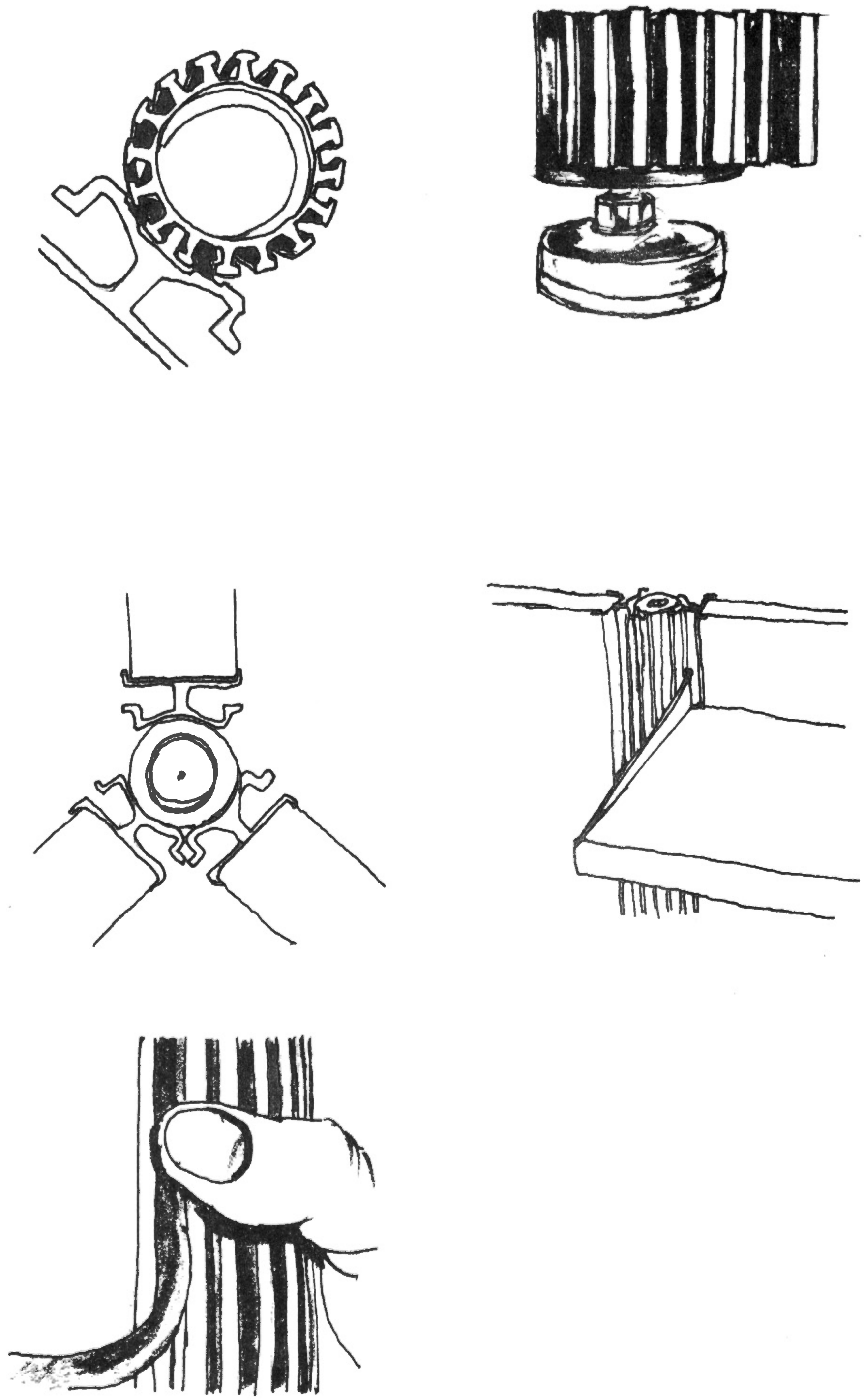


Figure 20. Technical Structure Showing Connectors

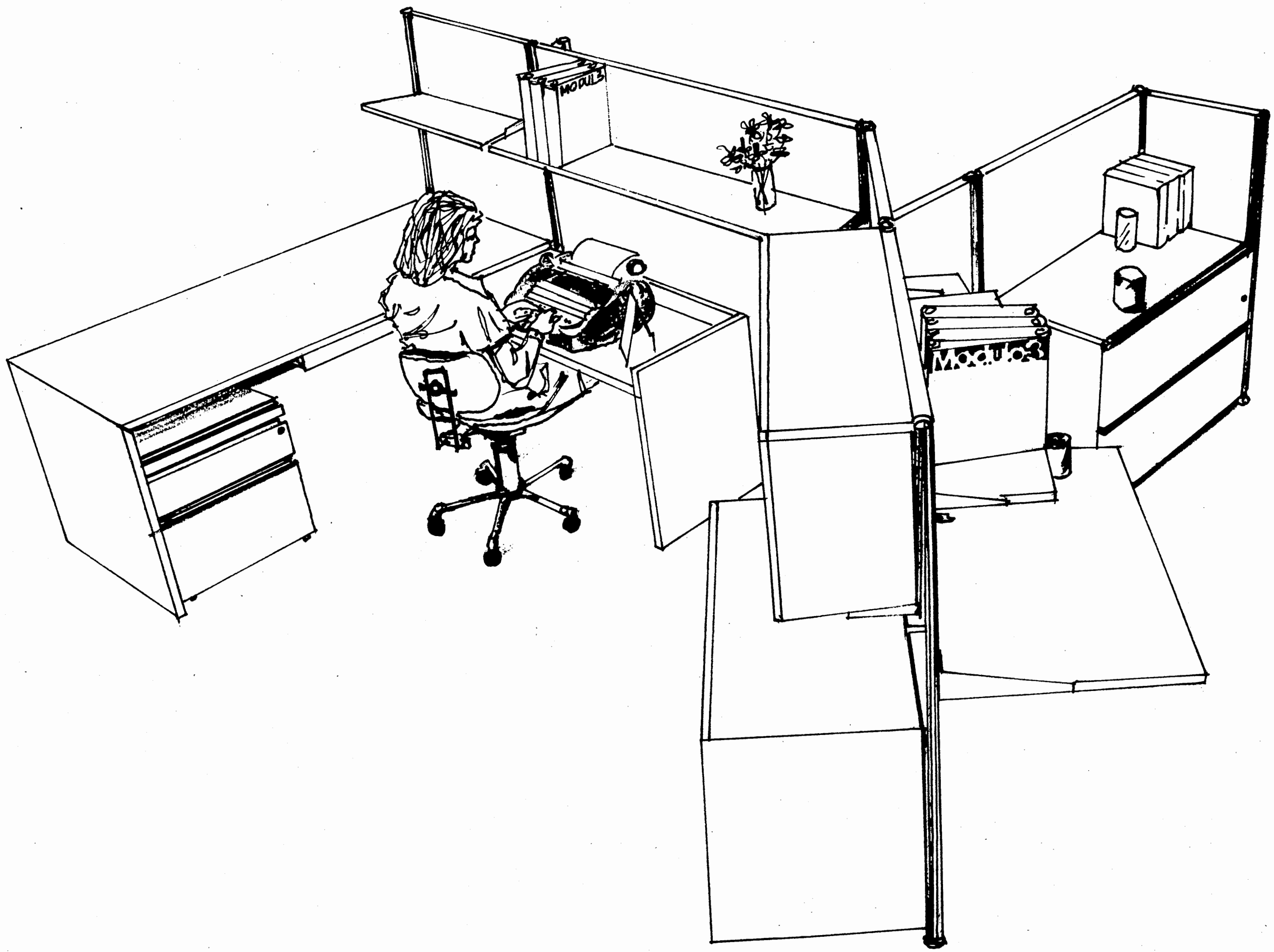



Figure 21. Planning Structures Showing Flexibility

opportunities to make mass produced modular furniture. This widespread development in modular practice has increased efforts in research and the development of modular standards. As these efforts take effect, the result will be an increase in efficiency of design and in the quantity and quality of construction of modular furniture.

Components (Figure 19) and connectors (Figure 20) and Packing (Figure 21) are also part of modular design. The Motta design (Figure 22) presents freedom of arrangement for use with maximum compactness for packing and transportation.

Other examples of modular furniture that possess these basic concepts of the "modular" include seating by Metropolitan Company, shown in two different arrangements (Figure 23 (a) and Figure 23 (b). Multigon seating shown in two different planning systems are based on a hexagonal module, 24 inches in Figure 24 and 32 inches in Figures 25 and 26. Jens Risom Design, Inc. presents seating groups particularly well suited for use in libraries, hospitals, clinics, airports, clubs, restaurants, banks or other public seating areas where functional design and interest are desired.

In studying these examples of today's modular furniture, it becomes obvious that they are an outgrowth of modular structural building systems, used together they express an integration of architecture and interior design which is capable of producing balance, beauty, flexibility, ease of maintenance, and compactability of man with his environment.

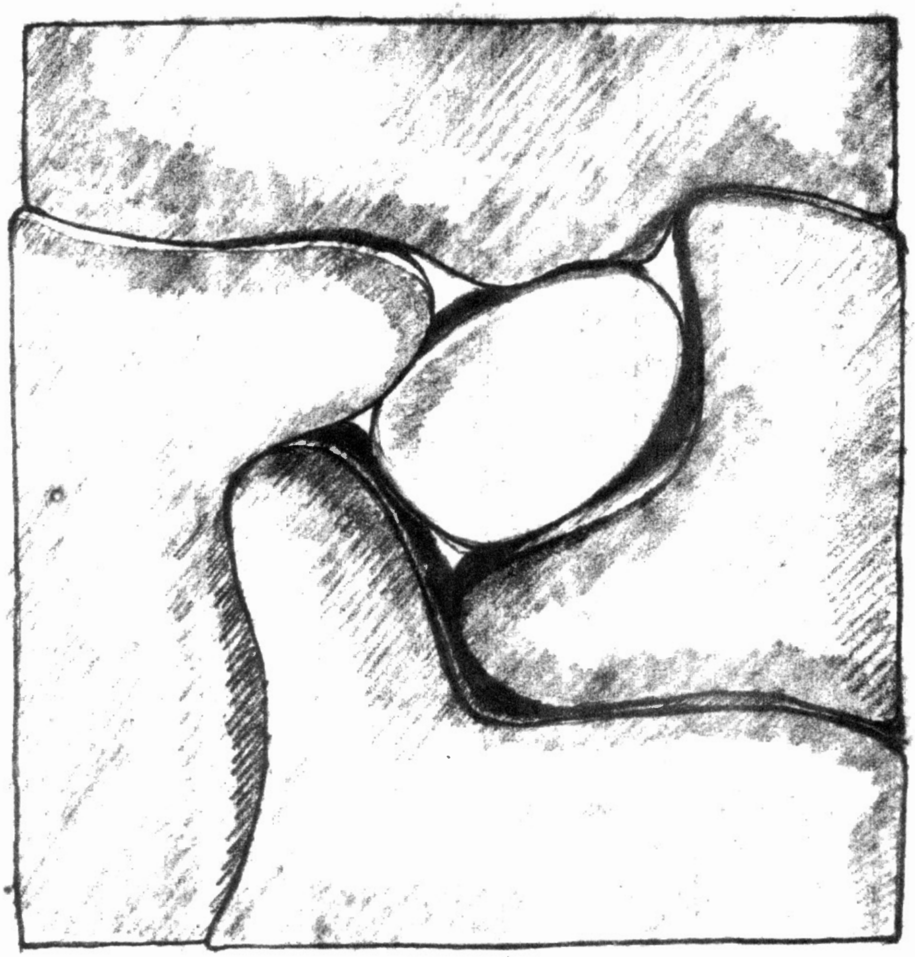


Figure 22. Malitte Lounge

A

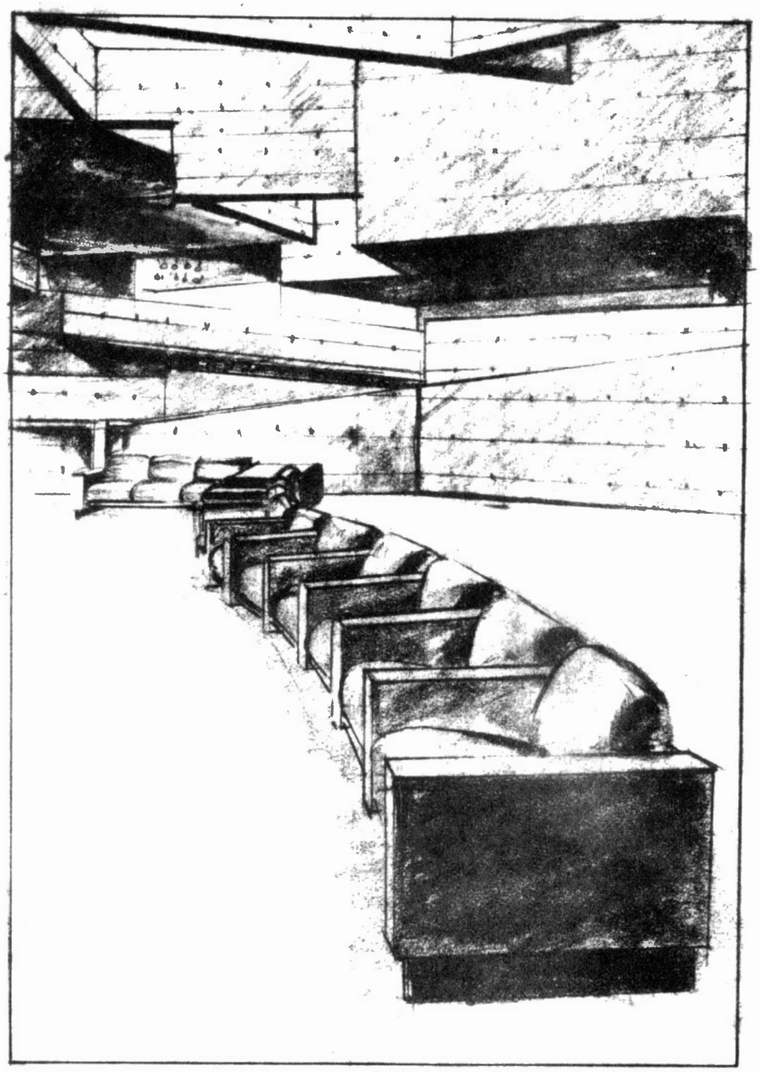


Figure 23. Metropolitan Seating Systems

B

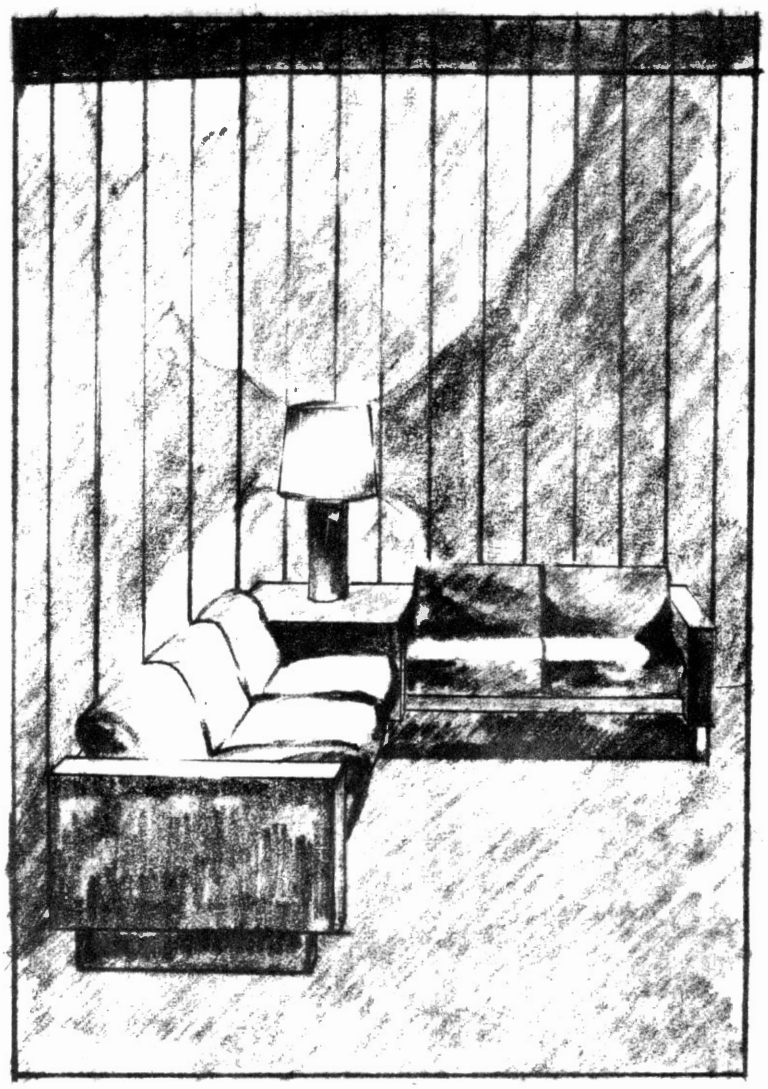


Figure 23. Continued

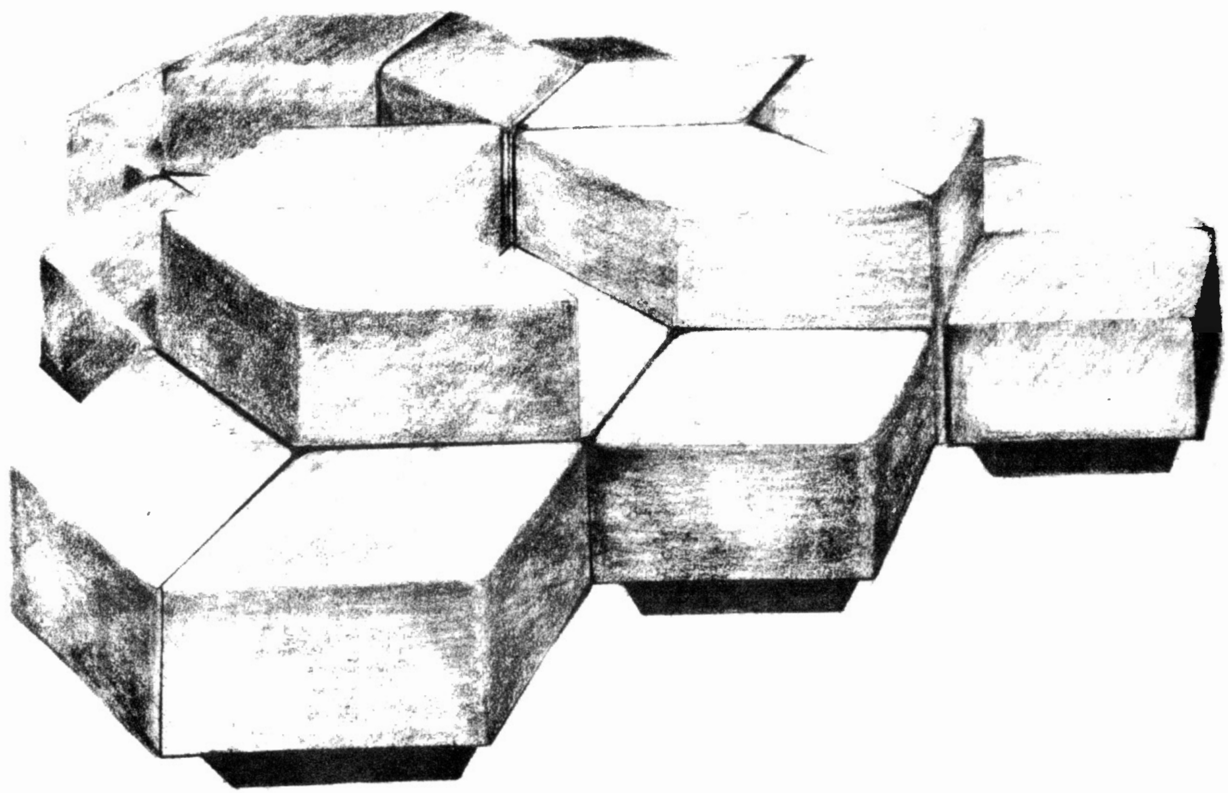


Figure 24. Multigon Seating Based on 24 Inches on a Side

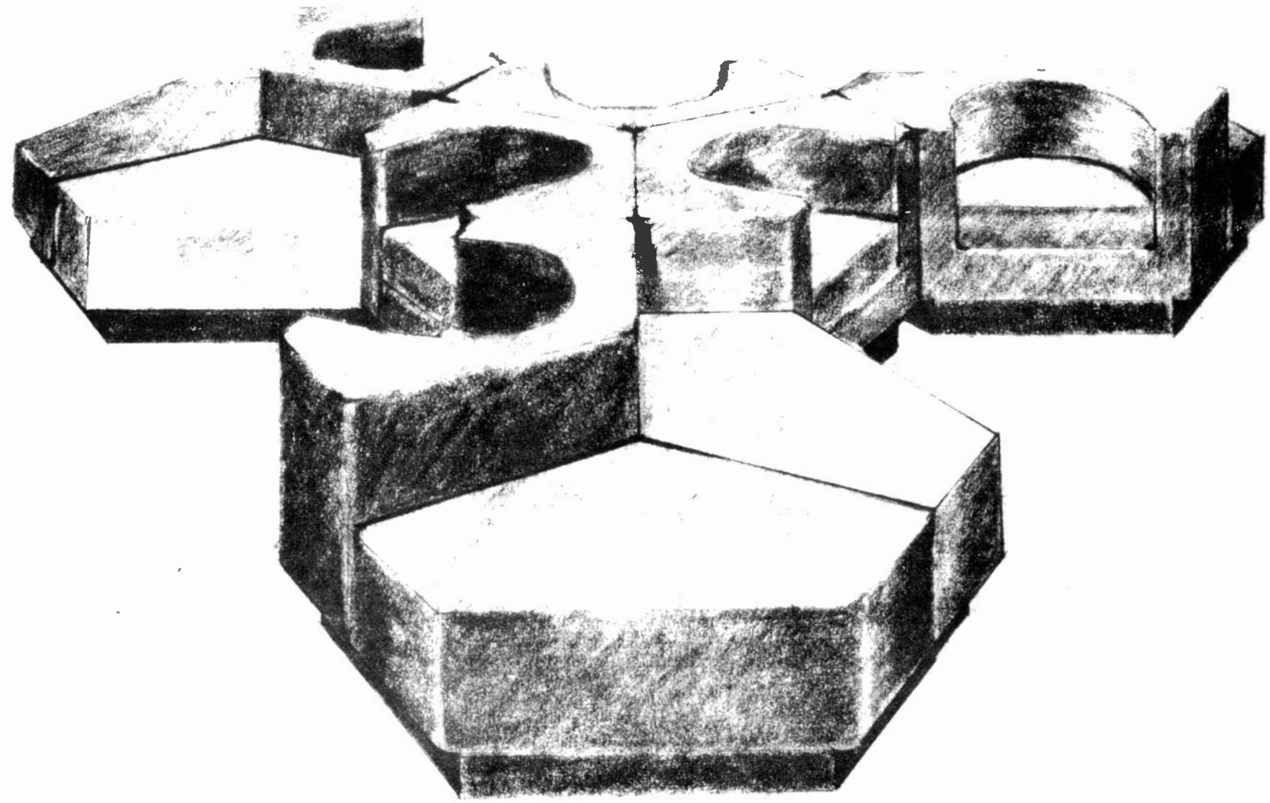


Figure 25. Multihex Seating System Based on a Hexagonal Module of 32 Inches on a Side

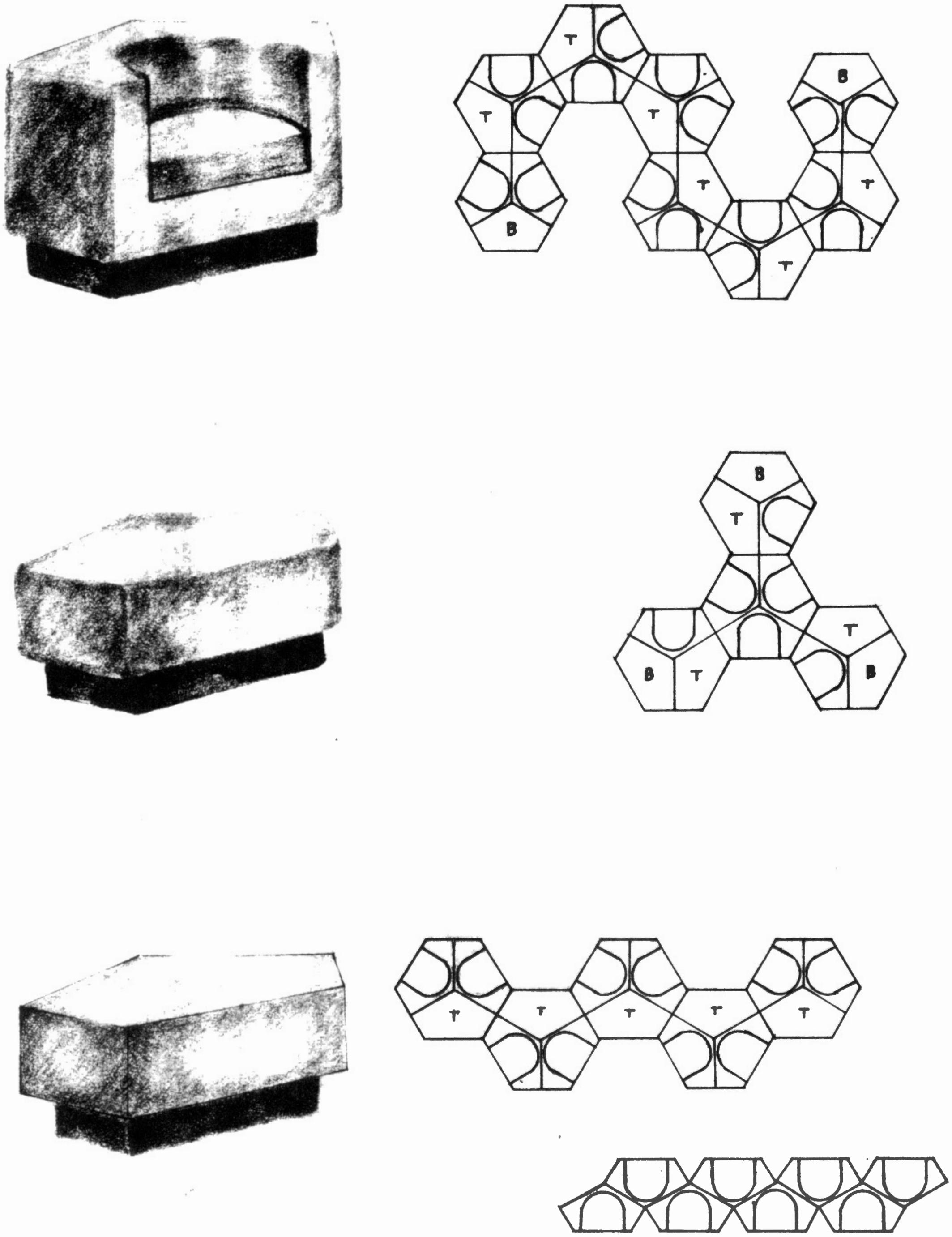


Figure 26. Multihex Seating: Components and Planning Module

FOOTNOTES

[1] Marjorie Elliott Bevlin, Design Through Discovery (New York, 1970), p. 314.

## A SELECTED BIBLIOGRAPHY


Ambasz, Emilio. Italy: The New Domestic Landscape. Greenwich: New York Graphic Society, Ltd., 1972.

Aptus Modular Seating Systems. San Francisco: Metropolitan Furniture Corporation, 1974.

Bevlin, Marjorie Elliott. Design Through Discovery. 2nd Ed. New York: Holt, Rinehart and Winston, Inc., 1970.

Cashen, Terrence. Multigon Seating. North Grosvener Dale, Conn.: Jens Risom Design,Inc., 1975.

Cashen, Terrence. Multihex Seating. North Grosvener Dale, Conn.: Jens Risom Design, Inc., 1975.

Cheng, Mei et al. Housing Systems. Cambridge: Massachusetts Institute of Technology Press, 1970.

Corney, John. Anthropometrics for Designers. New York: Van Nostrand Reinhold Company, 1971.

Darlington, Robert P., Melvin W. Isenberg and David A. Pierce. Modular Practice. New York: John Wiley and Sons, Inc., 1962.

Diffrient, Niels, Alvin R. Tilley and Joan C. Bardagjy. Humanscale 1/2/3. Cambridge: The Massachusetts Institute of Technology Press, 1974.

Le Corbusier. Modulor 2. Cambridge: Harvard University Press, 1958.

Le Corbusier. The Modulor. Cambridge: Harvard University Press, 1954.

Matta, Sebastian. Mallitte Lounge. New York: Knoll International, Inc., 1971.

Miller, Herman. Co-Structure System for Hospitals. Zeeland, Michigan: Herman Miller, Inc., 1972.

Module 3: The Integrated Panel System. Maryland Heights, Mo.: Tiffany Industries, Inc., 1974.

Ramsey, Charles G. and Harold R. Sleeper. Architectural Graphic Standards. 6th Ed. New York: John Wiley and Sons, Inc., 1970.

Schmid, Thomas and Carlo Testa. Systems Building: An International Survey of Methods. New York: Frederick A. Praeger, Inc., 1969.

Schmidt, John L., Harold Bennett Olin and Walter H. Lewis. Construction: Principles, Materials and Methods. 2nd Ed. Chicago: The American Savings and Loan Institute Press, 1972.

Space Standards for Household Activities. Champaign, Ill.: Illinois Agricultural Experiment Station, 1962.

Symposium on Precast Concrete Wall Panels. Detroit: American Concrete Institute, 1965.

The Current Status of Modular Coordination. Building Institute Research Publication 782. Washington, D.C.: National Research Council, National Academy of Science, 1960.

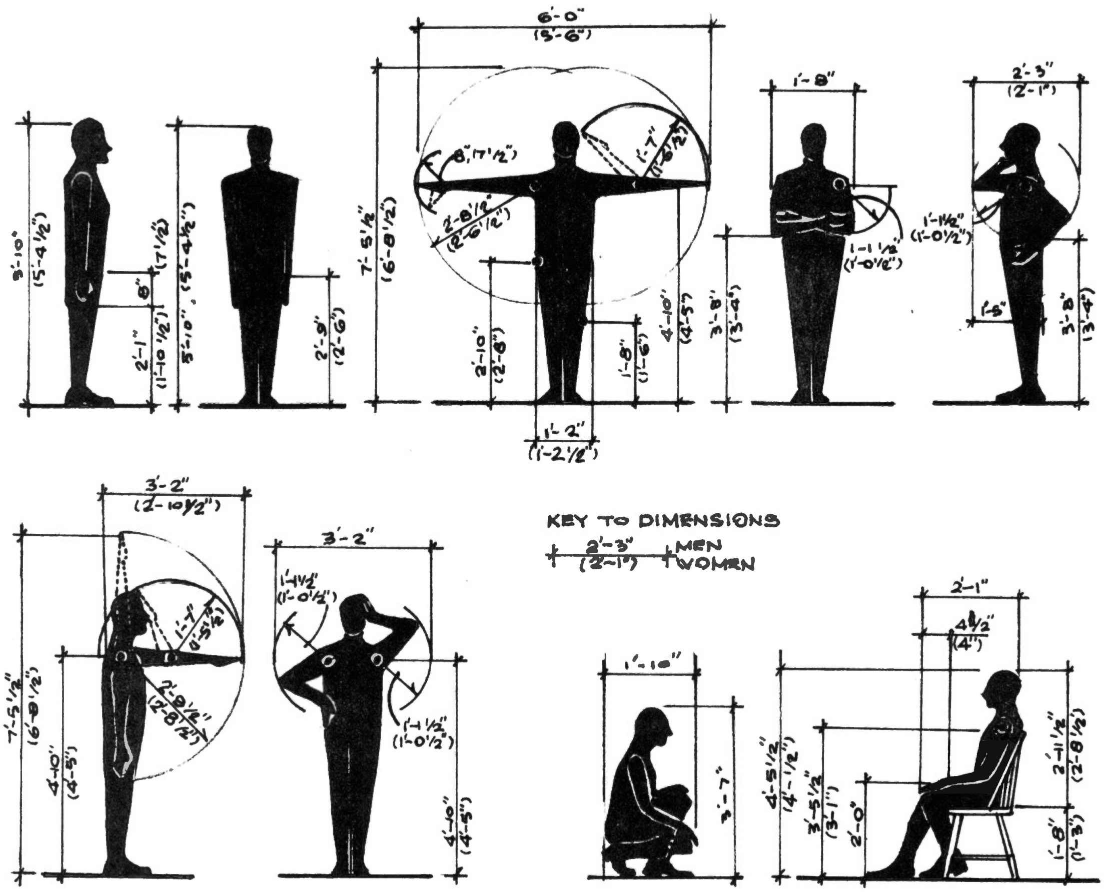
Watson, Don A. Construction Materials and Processes. New York: McGraw-Hill Book Company, 1972.

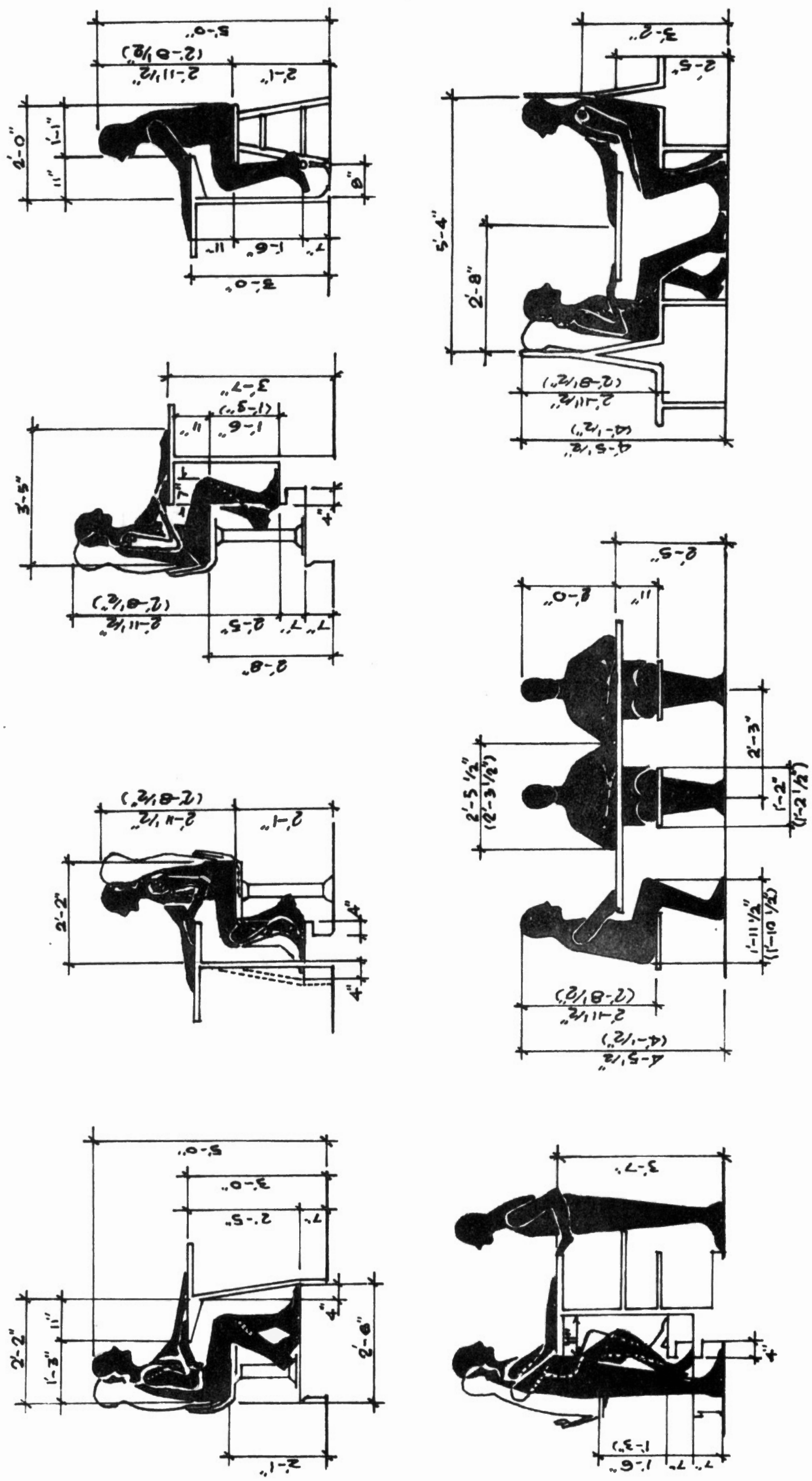
Webster's New World Dictionary of the American Language. New York: The World Publishing Company, 1957.

# APPENDIX A

# DIMENSIONS OF THE HUMAN FIGURE

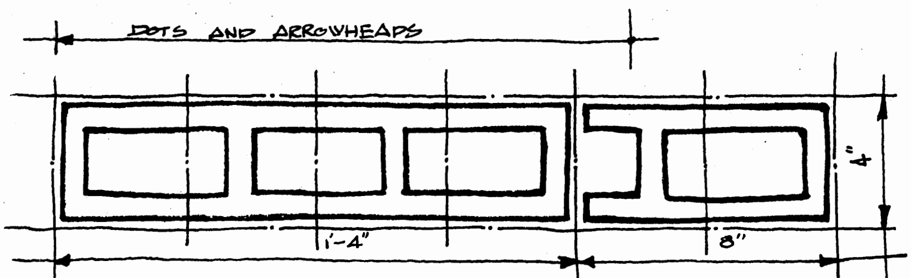
In regard to the detail and applicable data of human measurements the best resource that can be referred to is Humanscale 1/2/3 published by Massachusetts Institute of Technology Press, Cambridge, 1974.



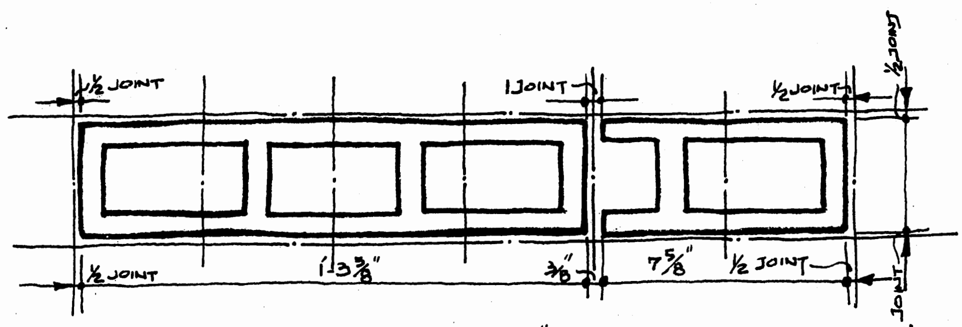


# APPENDIX B

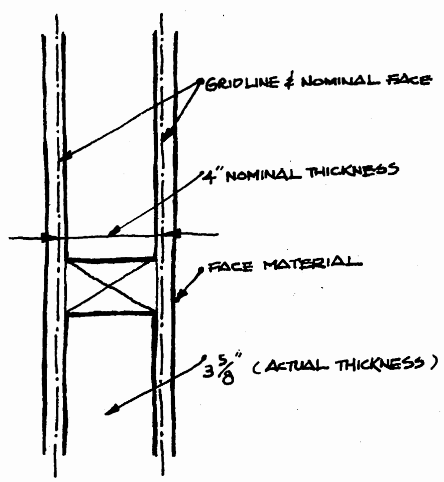
## NOMINAL AND ACTUAL SIZES IN BUILDING MATERIALS, COMPONENTS AND PRODUCTS



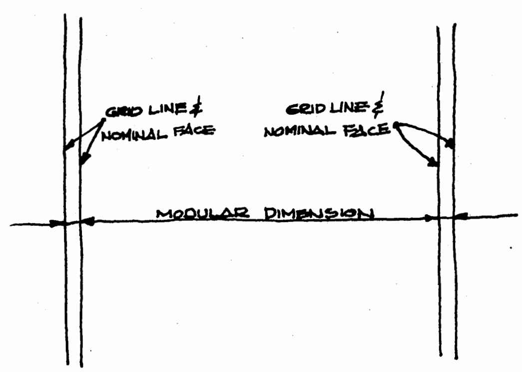

THESE ARE NOMINAL DIMENSIONS OF 4" BLOCK WALL 1½ BLOCKS LONG



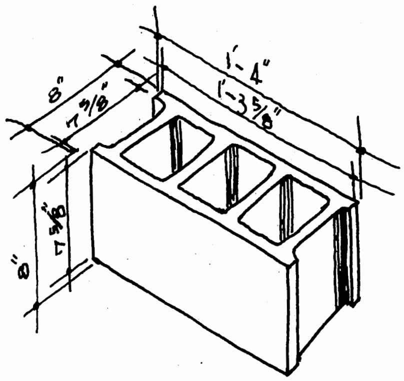

THESE ARE ACTUAL DIMENSIONS OF 4" BLOCK WALL 1½ BLOCKS LONG.



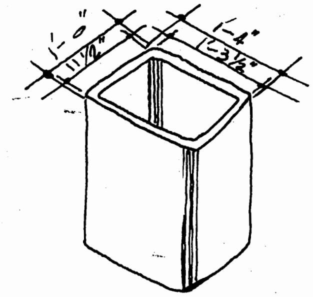

DIMENSIONING TO NOMINAL FACES (ON GRIDLINES) AND TO ACTUAL FACES.



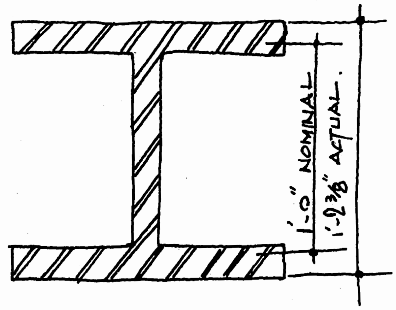

DIMENSIONING GRID LINES AT NOMINAL FACES.



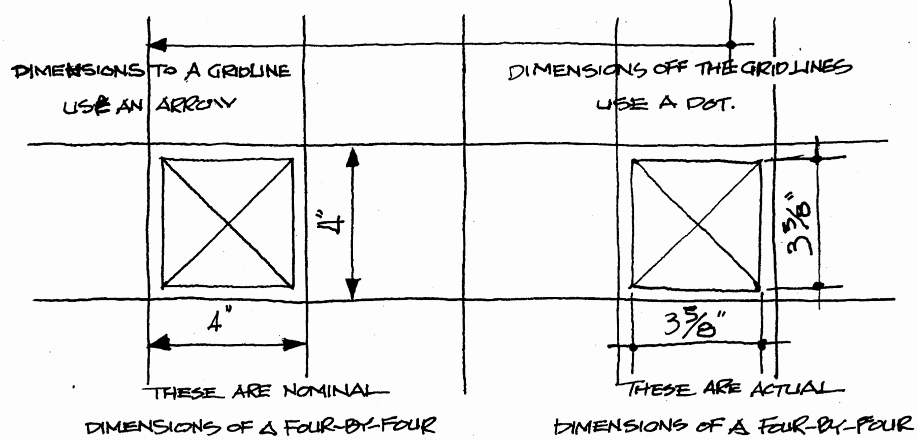

CONCRETE BLOCK.




FLUE LINER




ACTUAL SIZE LARGER THAN NOMINAL SIZE IN A STELL BEAM.



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