PREFABRICATED SYSTEMS
IN SCHOOL BUILDINGS

ABSTRACT

The historical development of the prefabricated systems of school buildings is reviewed. The origins of two of the leaders in the development of this system are discussed - The Consortium of Local Authorities' Special Programme (C L A S P) and the School Construction System Development (S C S D). The fundamental requirements of prefabricated schools are discussed with major emphasis on flexibility in the completed structure. Module and Modular designs of prefabricated school systems are the subjects covered in Chapter III, mentioning with emphasis, different concepts of both. A number of examples are presented for illustration.

The fourth chapter includes some of the actual prefabricated systems. The elements of construction have been traced in a pattern similar to other constructional work with some variations: foundations, systems of structure, components of construction and environmental control systems.

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School of Architecture

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Degree: Master of Architecture

March 1971

PREFABRICATED SYSTEMS
IN SCHOOL BUILDINGS

by

Cheng-Wong Chang

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the degree of Master of Architecture

School of Architecture,
McGill University,
Montreal.

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ACKNOWLEDGEMENTS

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INTRODUCTION

The increased needs of housing and education combined with the increase of population has brought unbalanced phenomena to society. Among these unbalances are a shortage of facilities such as housing and schools. The construction of buildings in the past was done in a traditional manner by handicraft workers. But, now, these workers can no longer meet the building requirements of society. Since the speed of handicraft construction neither satisfies nor overcomes the increased demand of society, handicrafted buildings can not hope to meet the requirements of society. Thus industrialization and standardization become necessary facts of life, and these must be carried on and developed. This concept applies to school building design too, and architect, planner, educator, and administrator should pay more attention and effort to it. Prefabricated building is one of the results of this attempt at up-dating. The field of school building is being transformed from the traditional manner to an industrialized and standardized one.

There are three additional reasons for constructing schools which are prefabricated in whole or in part. The first is reduced cost -- which can be achieved in prefabrication by careful design, quantity production and shrewd planning for a minimum amount of handling. The second is the speed of installation, which sometimes is startling even to the workmen who put prefabs up. The third reason is closely related to the second -- some prefab schools may also be taken down very fast and re-erected in locations of greater need.

Conventional builders have been accepting limited prefabrication since a long time. They recognized, for example, that a better and less expensive window sash could be produced in a plant than could be handmade on the job site. As builders become more aware of the time, labor, and materials that could be saved by prefabrication, they begin to use preassembled cabinets, prefitted doors, prefinished sink tops, prefinished floors and many other prefabricated parts.

Today, many of the successful companies construct homes by assembling prefab building panels -- exterior panels, partitions, floor system, ceiling system and roofs. The techniques of mass production are simply applied to production methods. The goal is to minimize custom-jobs without sacrificing the quality of construction.

For the purpose of more efficient construction, new materials have been developed which provide greater flexibility in use, and which are lighter and more uniform than traditional materials which were generally bulky and heavy. All building components which can be incorporated in virtually any architectural design, such as framing members, wall panels, floor and ceiling panels, lighting, and chalkboards are designed to be fitted together.

The full potential of school construction acquiring the use of prefabricated systems cannot be realised unless the design and building methods are examined together.

Although prefabricated systems of school construction have been partially employed in advanced Western countries such as England, the U. S. and Canada, it is hoped that attention and knowledge of it can be brought to countries such as Taiwan, the Republic of China, and other South East Asian countries in which education is growing in importance.

CHAPTER I

HISTORY

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The prefabrication of building is by no means a new idea. The word "fabricate" simply means "to put together". The combination of "pre" and "fabricated" indicates that parts of structure are put together beforehand, simply being erected on the site.

The beginning of prefabrication, in its simplest form, dates back to the time when primitive man cut and trimmed wood and tanned skins before he built a shelter (Fig. 1). In the early stages, it started with the use

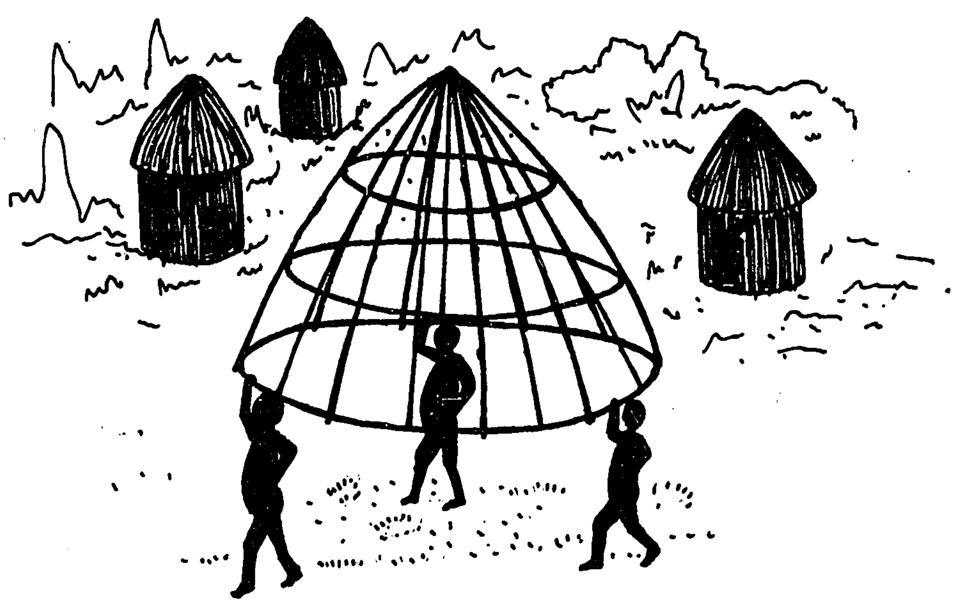

Fig.1. An early application of the principle of prefabrication

of iron as a structural material. Certain records of the prefabrication of building go back a great many years; for example, in the 1800's prefabricated buildings were used by Union Armies for barracks and small field hospitals during the Civil War (Fig. 2) (1-1). In the 1860's,

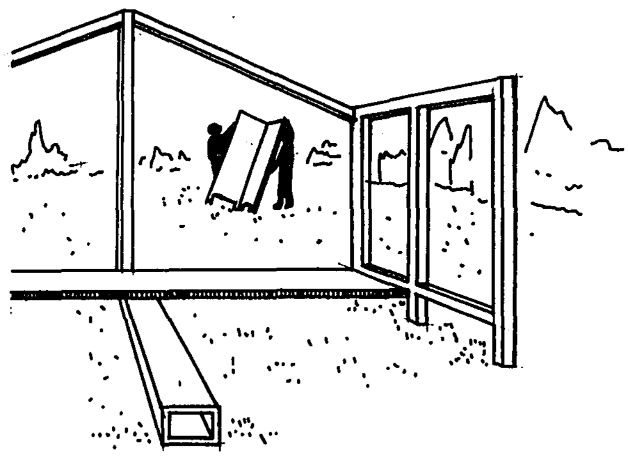

Fig. 2. Prefabrication techniques were used in the Civil War.

several American firms were reported to have supplied prefabricated buildings ready for erection (1-2). In the last 70 years the large panel system has been used in Europe and in the United States (1-3). But the proportion of prefabricated building remained at a low level until the 1920's. Through the twentieth century, almost until World War II, prefabrication became more popular for precut houses. Its use was a modified do-ityourself approach to home building. A few companies then ventured into prefabrication of a more complete house package including ceiling panels, wall panels, floor panels, complete with plumbing and electrical work installed in the walls (1-4)

The first prefab schools (some dating from World War I) were simply boxes, shipped by truck to the site and assembled quickly - whole walls at a time. Some prefabs of today are much the same (Fig. 3), deriving design concepts from prefab warehouses, gas stations and industrial buildings, to meet the great demand for classroom space (1-5). At the end of World War II, one school in every five was destroyed or damaged in England, and they needed to build or rebuild their schools to meet the new demand (1-6). This kind of prefabricated school was continued, in order to meet the need of the despairing community with its heavy school burden.

In 1946, the first prefabricated school building system based on a steel frame with brick walls was developed by architects on the staff of the Hertfordshire County Council in England. At that time, the County estimated that in 15 years time, 175 schools would have to be built to educate the growing population (1-7). In 1949, a concept of

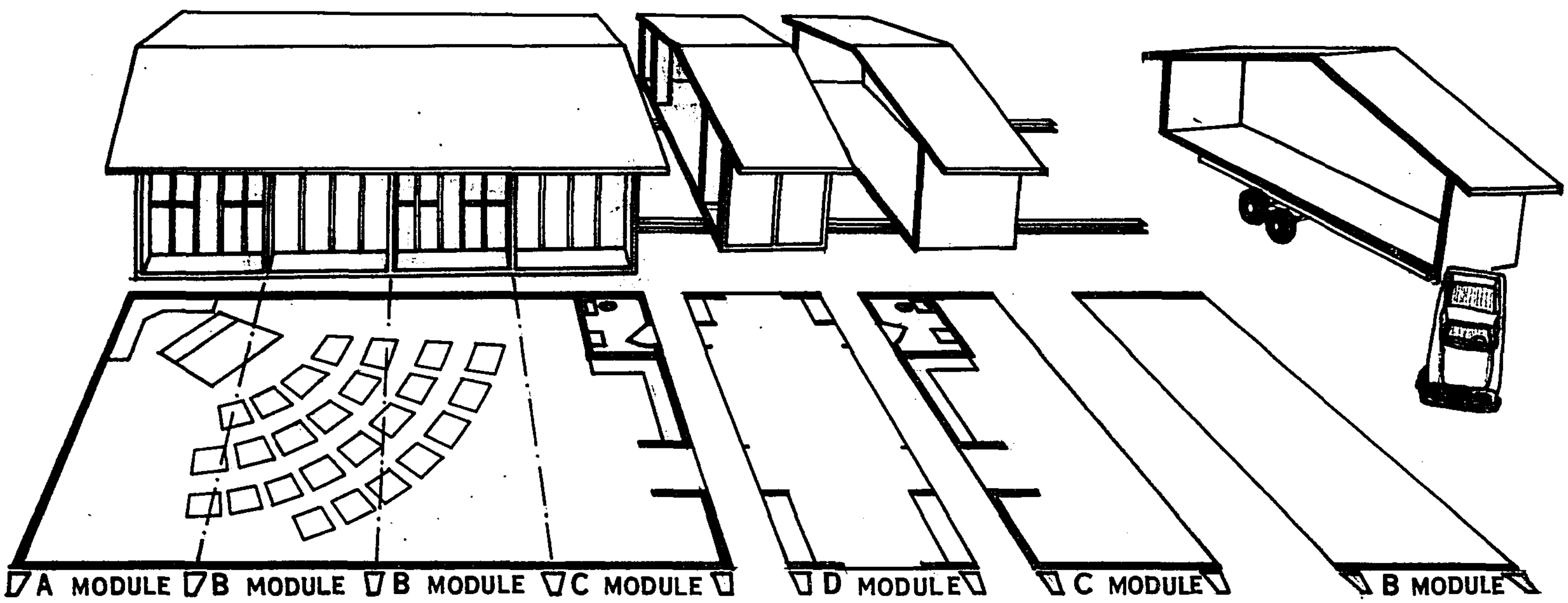

Fig. 3. Double classroom unit consists of nine modules.
Newark Public School, Newark, Ohio, U.S.A.

development work was undertaken by the Development Group at the Ministry of Education in London. Some of the larger manufacturers and contractors have followed this concept and set up their own development groups - architects have often been included among them (1-8). In 1956, the well-known consortium, C L A S P was established by architects of the Nottinghamshire County Council. C L A S P was formed to enable the full economics of factory production methods to be realized. Although there are a dozen systems of industrialized building available for school construction, they all have to conform to the national cost limits set by the Ministry of Education. In 1957-1958, 11 schools were started (1-9).

In the United States, the first prefabricated system was S C S D. This system was established in late 1961 to help in the development of American school by Educational Facilities Laboratories, Inc. - a non-profit corporation founded by the Ford Foundation. The S C S D system as evolved from the British system after a series of mutations, has finally became a much different system. The British system was designed by the architects employed by local authority offices, and had incorporated all the building elements. This approach was found to be unsuitable in the United States with its different social, economic, political, professional, industrial and administrative factors (1-10).

The first S C S D project school began its construction on October 19, 1965 and was completed by February 1, 1966. Named the Fountain Valley High School, the 3,000 students school which opened in the fall of 1966 & belonged to the Huntington Beach Union High School District, was designed by architects Neptune and Thomas. In 1966-1967, another 11 schools were built in California using this system (1-11).

In Canada, the first prefabricated system was S E F. This system is similar to S C S D system in construction, it has been developed by the Metropolitan Toronto School Board Study of Education Facilities, sponsored by the Metropolitan School Board, Educational Facilities Laboratories, New York, U. S. A., and the Ontario Department of Education. Since 1967, after less than three years of studies, meetings, research, design, tendering and negotiating, the S E F technical test project - Eastview Public School in Scarborough, Ontario, was completed in October 1969, while the first S E F complete test school - Roden Park Public School, Ontario, was completed later in February 1970 (1-12). Since that time several other schools have been erected in the Metropolitan Toronto region.

A prefabricated school system exists also in France. The architect is Ateliers Jean Prouve - well known in France for his construction elements. He has studied the problem of providing special elements for the quick construction of classrooms or school group buildings, while leaving considerable freedom of planning to the architect or builder, Prouve's concepts have been adopted as the Standards by the French Ministry of National Education. By using this system, many schools in France, such as those destroyed during the War, and others in economically depressed regions, were built or rebuilt. An example of this is the nursery school at Martigues (Fig.15), designed by the architectural firm of A. Arati, M. Boyer and C. Lestrada (1-13).

In addition to the prefabricated systems discussed above, there may exist other systems in other countries. However, none were found in the available literature. There were a few articles about the C L A S P system used in Italy (1-14) and in Germany (1-15).

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CHAPTER II page

FUNDAMENTAL REQUIREMENTS OF PREFABRICATED SCHOOLS

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FUNDAMENTAL REQUIREMENTS OF PREFABRICATED SCHOOLS

The prefabricated system must provide for flexibility in organization, in planning, in construction and in future changes (2-1). Future changes are unpredictable, but if more flexibility within the building plan is permitted, changing the layout would not effect the buildings superstructure itself. At the same time the cost of alteration would be kept at a minimal.

2.1 Planning

Today, the most desirable school buildings are those that have simplicity in style, flexibility in design, and are indigenousness to the region in which they are located (2-2). School buildings should be functionally flexible in order to ensure free development (2-3). The planning should be made, both with regard to space and to construction so that it can be adapted to developing and changing needs. A building can thereby, serve its purpose for a longer period. This necessitates a careful design in the planning stage.

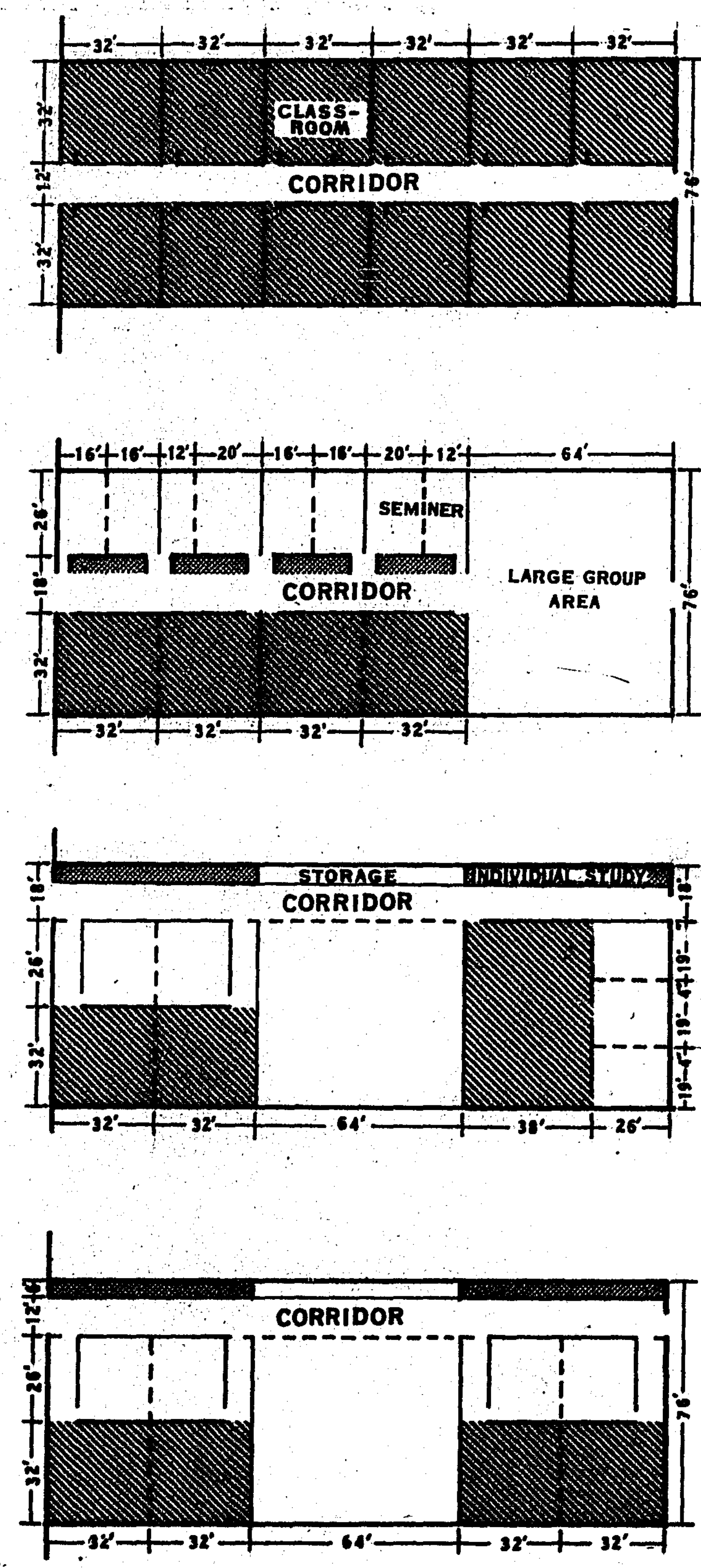

Fig. 4

Flexibility in school planning

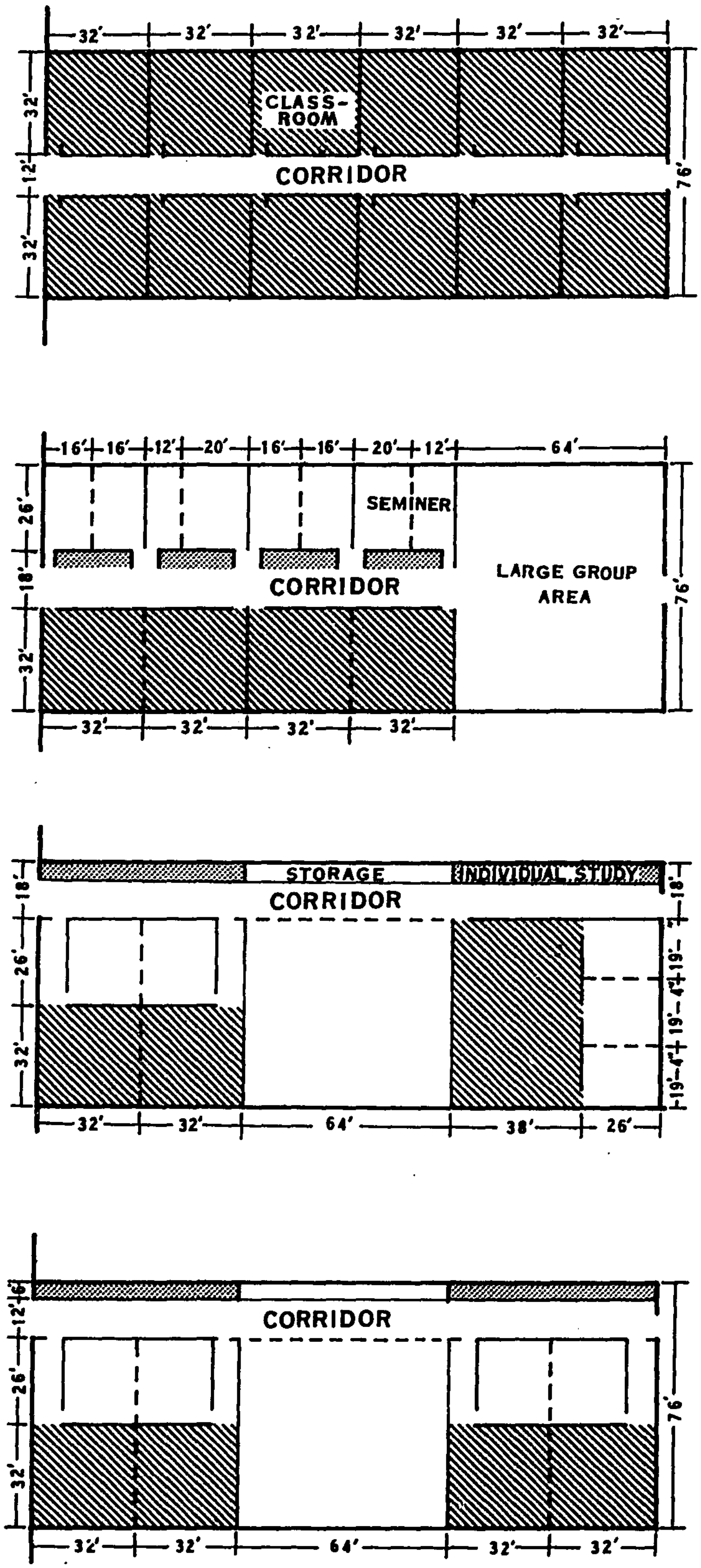

Fig. 4
Flexibility in
school planning

1st stage

2nd stage

3rd stage

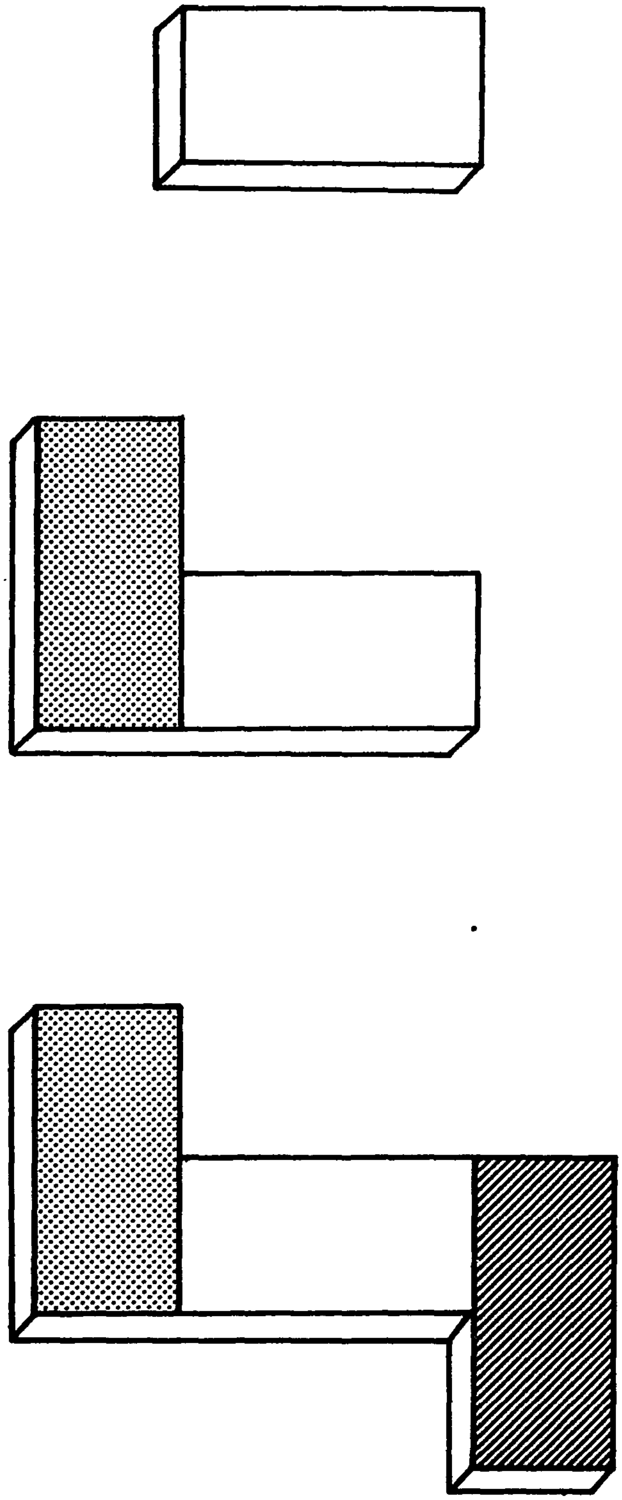

Fig. 5. Expansion

The construction work should permit internal (Fig.4) and / or external expansions (Fig.5) to adjust according to new educational needs in the future (2-4). Although every school is designed and built for its own educational purposes or specific programs, the ever increasing needs for education requires that new teaching methods be tested and modified. The curriculum in the school will not remain static, for new subjects and new teaching methods, new inventions and new equipment will be introduced to the school and these will affect its curriculum. In order to conduct tests for idealized room size and other desired educational changes, more flexibility is needed within the planning of the school building (2-5).

Nowadays, schools should not be designed for present need alone. They should be so planned and built so that they can adapt to the development of new pedagogic conceptions and demands. It seems necessary to design and construct schools in such a manner so as to permit modification, and to meet new purposes. Every advantage should be taken of new methods of construction which insures alteration at minimum cost.

2.2 Construction

School building construction today is based not only on pedagogic requirements but is based also on economic grounds. There are many different schemes which can be used in school construction. For example, if the school building is constructed by using light steel frames (Fig.6) and long-span beams, the resulting building will have a large amount of space which can be divided into any size of room as needed (2-6). This can be accomplished by using non-load-bearing walls which can be removed and re-erected without

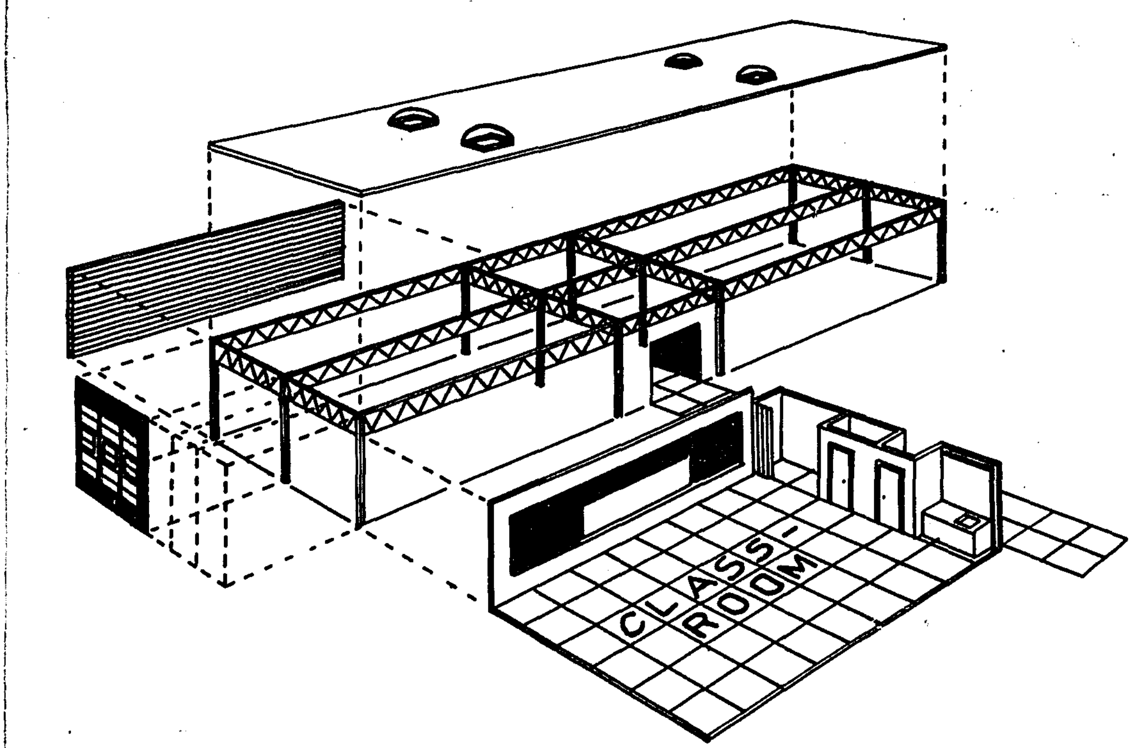

Fig.6. Light-steel framework permits flexibility in design.

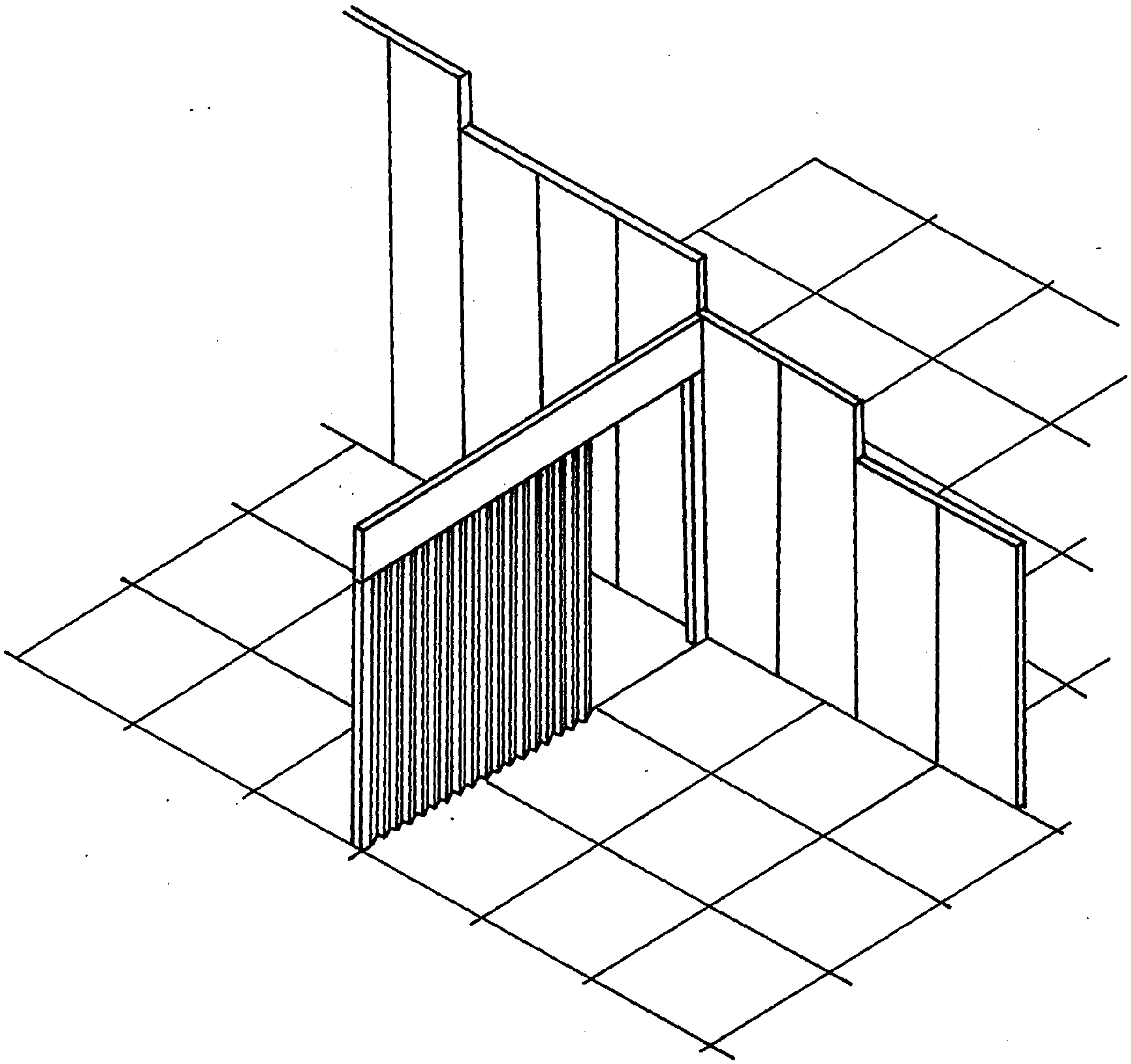

Fig. 7. Demountable and fixed partitions are provided in heights of 10, 12, 14 and 16 feet, and operable partitions in 10 and 12 feet heights.

effecting the building structure (2-7). Movable partitions (Fig. 7) which can be used as dividers between rooms make possible a more rapid change of room size for accommodation of changes in activities or in group size. In other words groups can be separated or brought together easily (2-8).

2.3 Environmental Control Systems

The environmental control systems must be planned and designed for each building. The environmental control systems include lighting, heating, ventilating and air-conditioning. A satisfactory arrangement and design of this system will not effect freedom of space. In order to avoid considerable defects, these systems should consider such components as movable units (Fig. 8) and flexible supply systems (Fig. 9)

A more detailed discussion of Construction and Environmental Control Systems followsin Chapter IV.

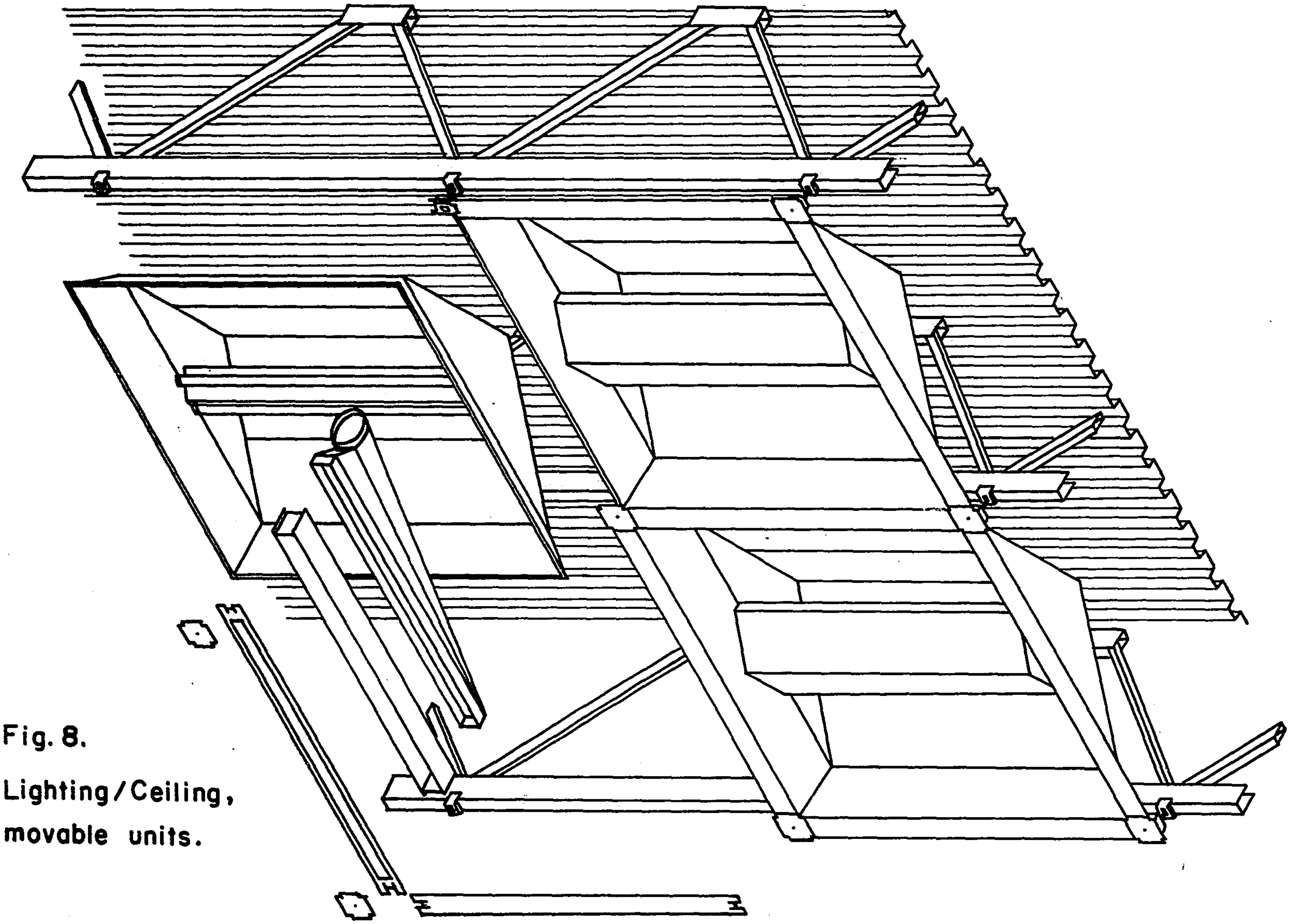

Fig. 8.

Lighting/Ceiling, movable units.

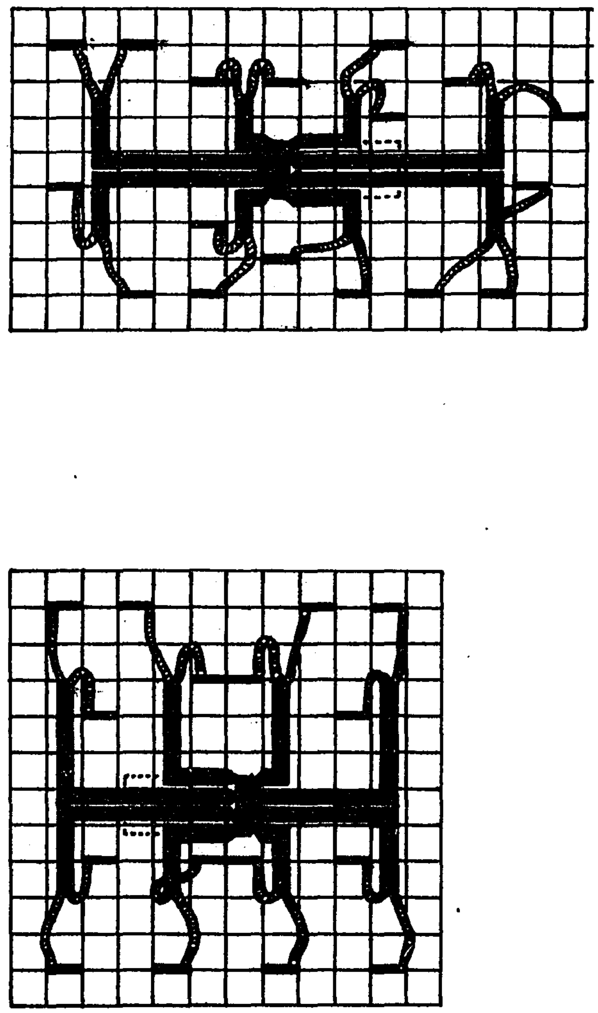

Fig. 9. Flexible Duct System

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CHAPTER III page

MODULE AND MODULAR DESIGN IN PREFABRICATED SCHOOLS

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MODULE AND MODULAR DESIGN IN PREFABRICATED SCHOOLS

The word "module" means a common unit of measure particularly specified for dimensional co-ordination (3-1), and the word "modular" characterizes a module of design and proportion (3-2). The modular approach can help in a logical, efficient organization of the building space and of the building materials, components, structure, and equipment which define the spaces and service them.

Since prefabricated systems have contributed to the remarkable increase in building productivity, module and modular design with its components has led to a more rapid design, manufacture and erection of building.

The advantage of using the module and modular system in the design of buildings is that, for contractors: the modular dimensioning offers less cutting, ease of plan comprehension, less waste and ease of erection; for architects and engineers: fewer drafting errors, clearer detailing, and faster production of construction documents; for general contractors: closer cost estimating and quicker job-site lay-out (3-3); for students and future employers in architectural offices: a tool for measuring (3-4).

The availability of modular materials makes it profitable to design modular building. The manufacturers should produce modular materials before using any modular dimensioning in the building (3-5). The construction industry has begun to realize that the module can free them from restrictions, instead of hampering them (3-6). This has substantially contributed to the success of programmes, such as the prefabricated school programme of England, which owned its reputation by using modular design (3-7).

3.1 Basic Module

The inch and foot or centimeter and meter have long been established as common units of measure by international agreement. It is most important that a common measuring system be used by architects in the design of buildings and by manufacturers in the manufacturing of their products. A common unit of measure for both architects and manufacturers was required in order to accurately and conveniently co-ordinate the dimensional parts of buildings.

The new unit was called the module. In 1945, the

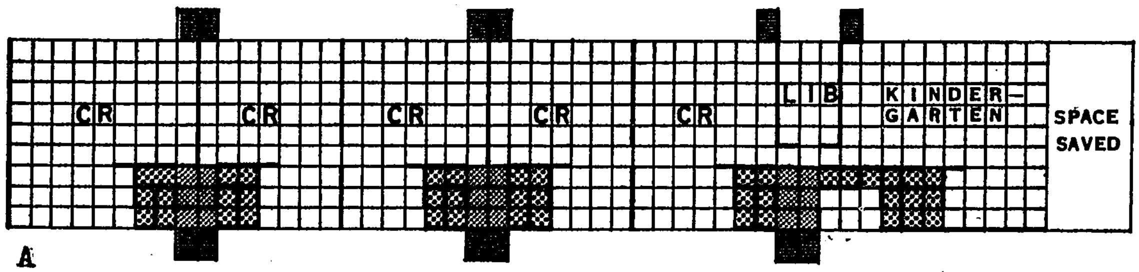
American Standards Association adopted a basic module of 4 inches to encourage the use of single basic unit for every building, and to provide a basis for the sizing of materials and components (3-8). This basic module is small enough to allow flexibility in design, and the techniques of module-dimensioning system enables the separation of this module whenever necessary.

From the results of studies in different parts of the world, the dimension of 4 inches, and in countries using the metric system 10 centimeters, has been found most satisfactory (3-9). When all products of manufacture are produced in conformity with the standard module co-ordinating unit, all building dimensions can be established during the early stage, and the majority of the products chosen for the building can be easily co-ordinated with these dimensions.

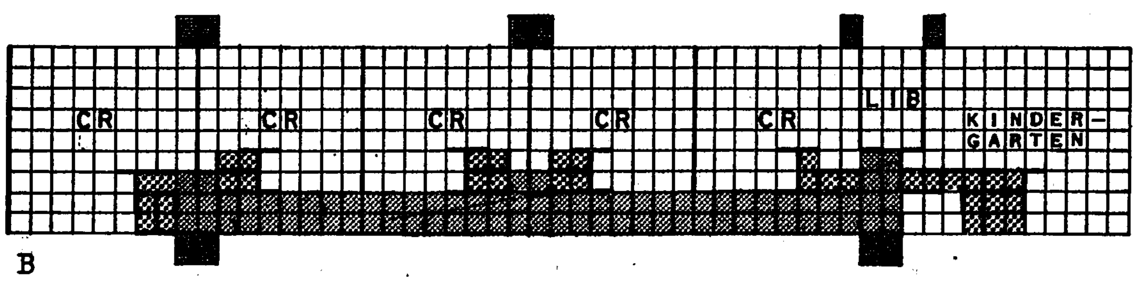
3.2 Planning Module

The module design in planning of the building, is sometimes called the planning grid or design grid, and its basic meaning is to achieve a logical solution to control the plan.

In the planning design of school building, factors



Plan A shows the advantages gained by providing separate lobbies for each pair of class-rooms with a "concealed corridor" created by doors between rooms for occasional visitors or teacher traffic.



Plan B shows how the 9-module width works out for a conventional sidewall corridor scheme.

Fig.10. Module design in school planning.

such as difference of sizes, shapes, dimensions of rooms, and school area can be easily controlled by using the planning module (Fig.10). If a single planning grid can be fitted repetitively into rhythmic patterns in the planning and structural elements of the building, then the design and construction of the building will be more efficient and simple (3-10).

The great advantage to the architect in using a planning grid in design is its simplification in preparing the drawings. It is also easier for the draftsman to translate these drawings. These design or planning grids are necessary for the decisions of manufacturers in producing the parts of the building (3-11).

3.2.1 Planning Module in Prefabricated Schools

The module design permits a very high degree of freedom and flexibility in plan, design and structure of buildings. Most prefabricated schools have used module design to develop the requirement of the building.

In England, the prefabricated school in Hartifordshire, had a module as big as 8'-3" (related to the length of a classroom). Later, most groups such as the C L A S P

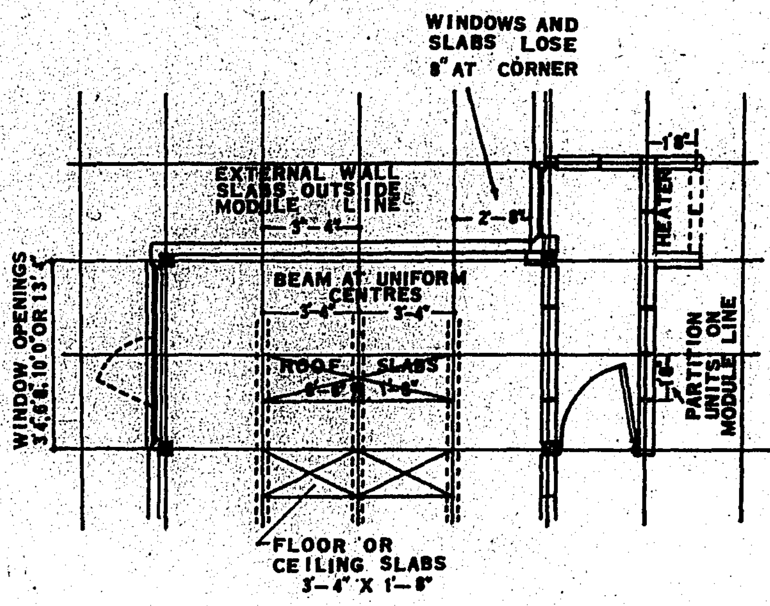


Fig.11. The planning basic on 3'-4" module which shows how any multiples of modular size can be grouped in any plan shape desired, using a limited number of standard parts.

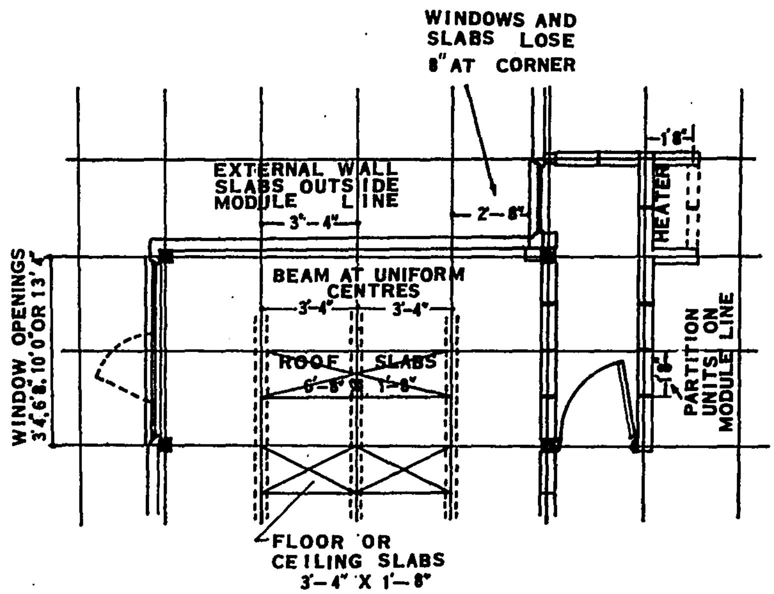


Fig.11. The planning basic on 3'-4" module which shows how any multiples of modular size can be grouped in any plan shape desired, using a limited number of standard parts.

basic space module

intermediate classrooms

kindergarten-administration

multi-use

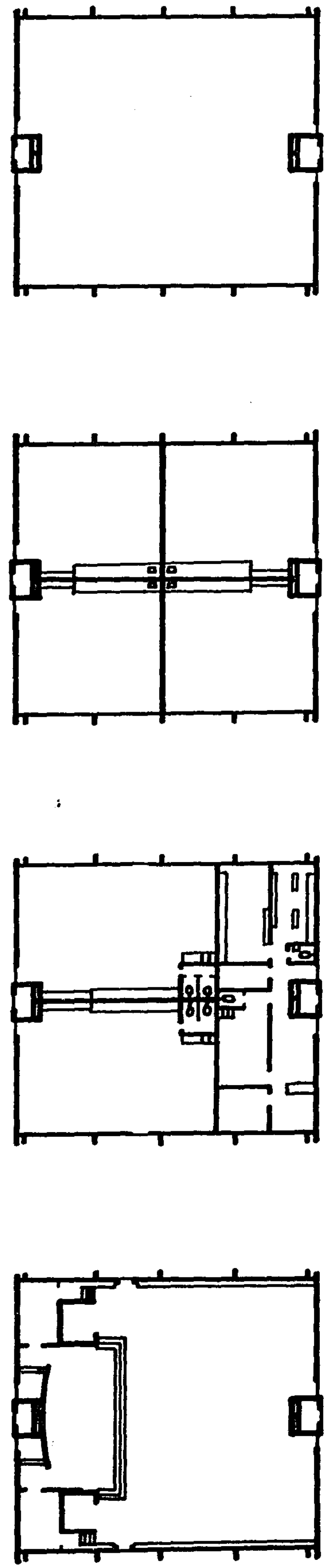
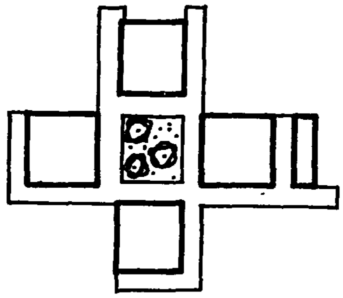
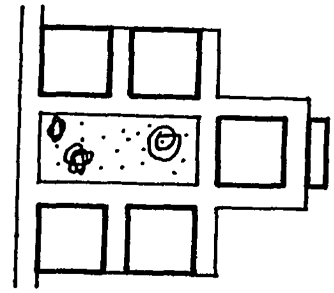


Fig.12. the basic space module (BSM).

continued.

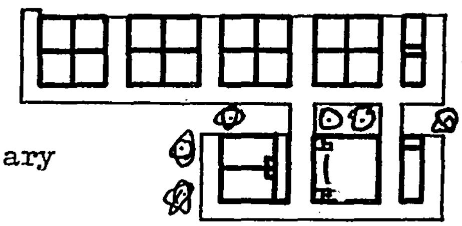


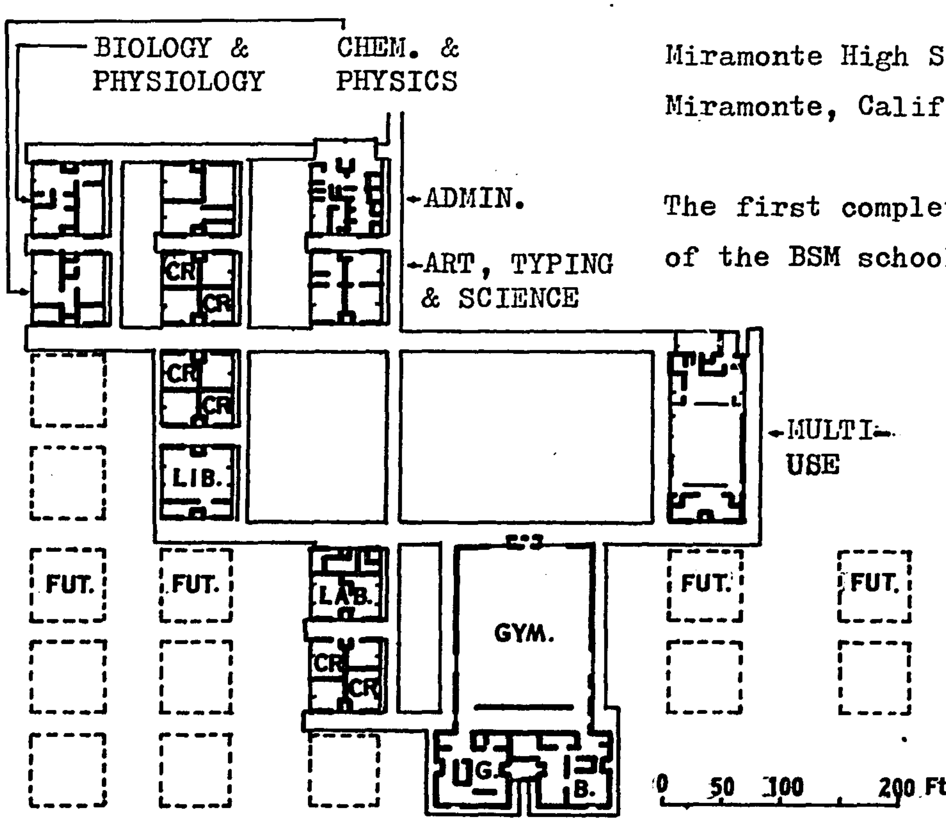
Cluster scheme - shows sample classroom and laboratory grouping for a big campus school.



Mall scheme - illustrates another sample grouping for a campus high school.

Row scheme - shows how space modules are organized in an 18-classroom elementary school.





Miramonte High School,

Miramonte, Calif., U.S.A.

The first completed example of the BSM school.

system have generally employed the 3'-4" module (Fig.11) for schools. The 3'-4" module can adequately meet the wide range of different requirements in educational buildings. For example, the external wall can change direction at intervals of 6'-8", 10'-0", or any combination of these two dimensions, and steel columns can be located at any intersection of the 3'-4" square grid: partitions are centered on grid lines, with their faces 4 inches to either side. Changes in partition direction can be made at 3'-4" intervals. Window sills are either 2'-0", 2'-8" or 3'-4" above the finished floor. Transoms and door heads are 6'-8" with floor-to-ceiling heights being 8 feet, 10 feet, 12 feet, 14 feet or 16 feet (3-12).

In the United States, there are many different sizes of planning module, but most of them are according to the multiple of 4" basic module (3-13). The architect, E. Kump, of San Francisco, recommended a basic space module (BSM) (Fig. 12). This concept is basically simple, and uses a 4 foot module as the planning grid. It means: (1) fixing upon a space and shape that will accommodate any combination of the functional space needed (and that it will also accommodate a regular component-module of, say 4 ft.); (2) spanning this space so as to leave the interior flexible; and (3) then

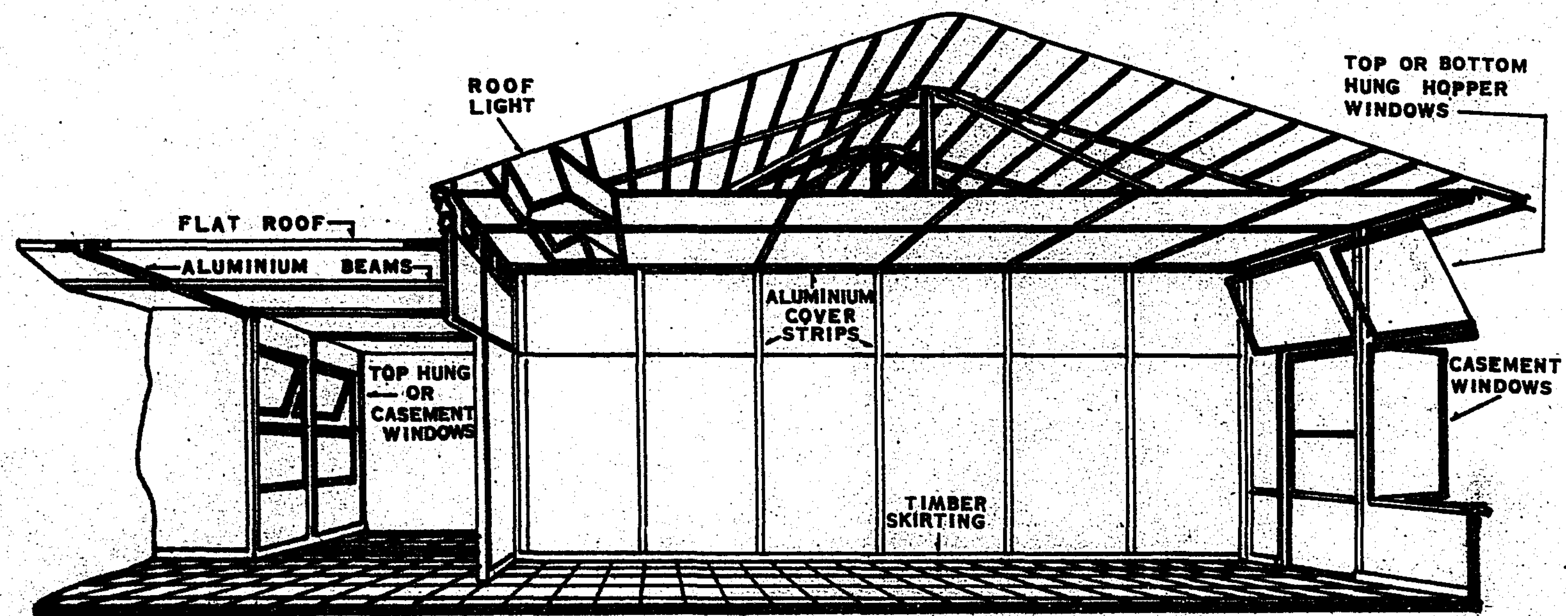


Fig. 13. Prefabricated Aluminum School
Bristol Aeroplane Company System, England

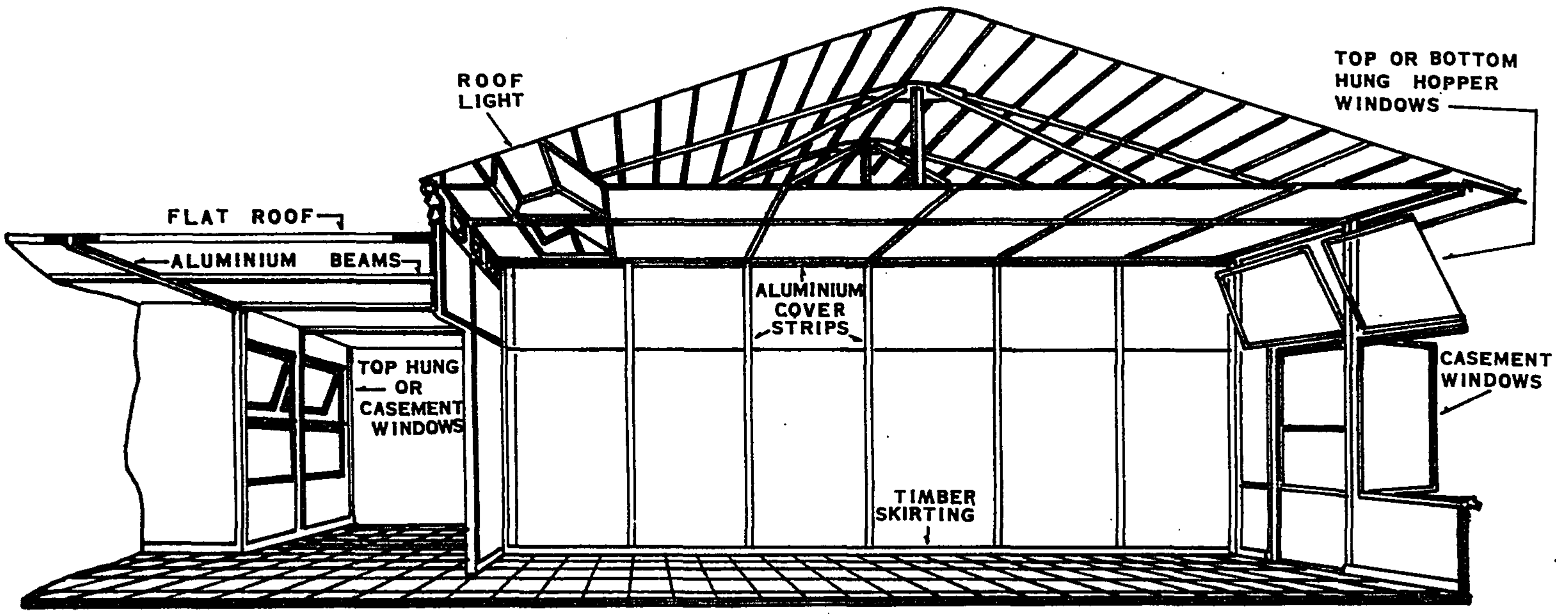


Fig. 13. Prefabricated Aluminum School
Bristol Aeroplane Company System, England

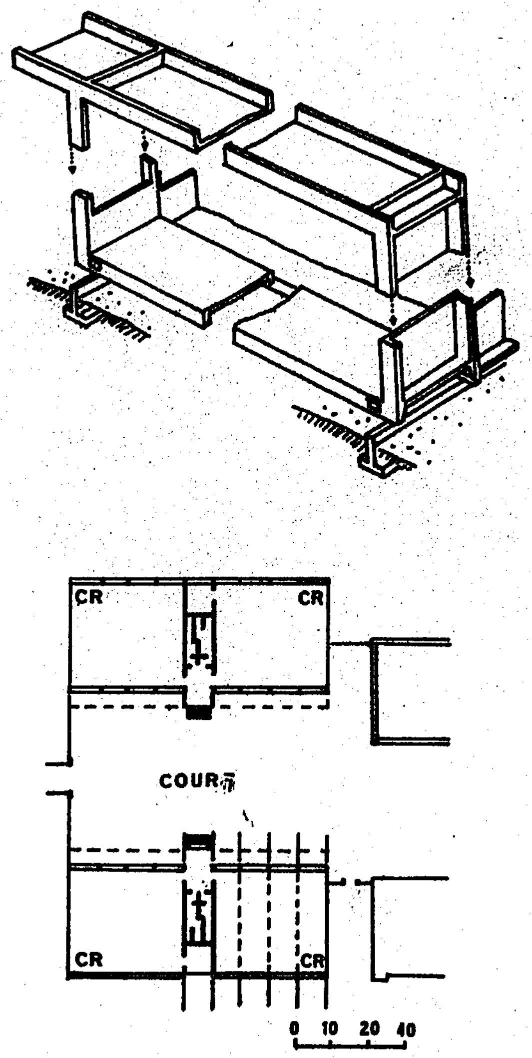


Fig.14. Demountable classroom units in concrete for the Homewood Elementary School, Pittsburgh, U. S. A.

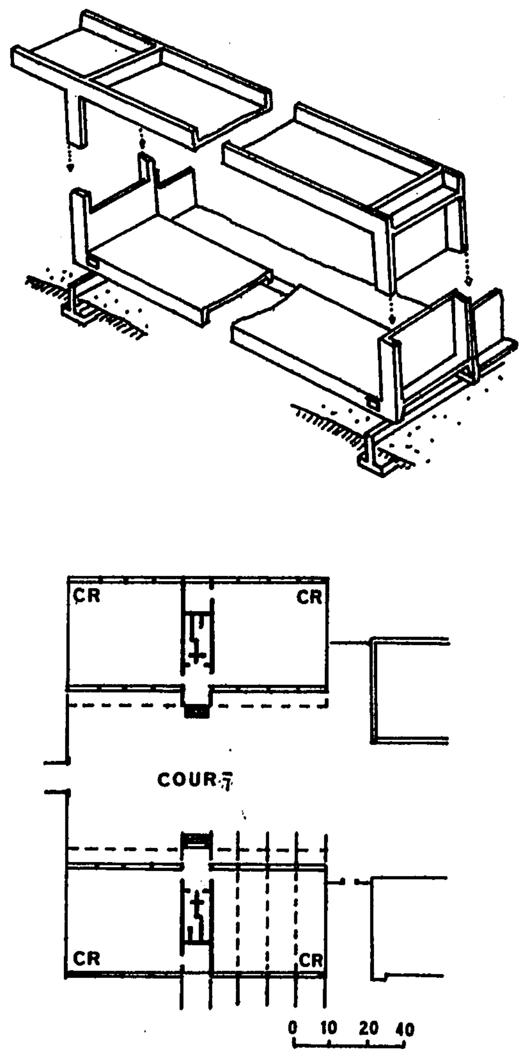


Fig.14. Demountable classroom units in concrete for the Homewood Elementary School, Pittsburgh, U. S. A.

repeating this identical enclosure of space as often as necessary (3-14).

Similar to the BSM concept, the prefabricated school in England also uses a 4 foot module, such as the Aluminum School (Fig. 13) in Lockleaze, Bristol, England, designed by the Bristol Aeroplane Company (3-15).

In addition, the 8'-0" planning module is also used in the United States, such as the Homewood Elementary school (Fig. 14), Pittsburgh (3-16), and several School Districts in Southern California (3-17). In recent years, 5 feet planning modules have been used by S C S D system in Projects and schools, such as the Barrington School, Illinois (3-18), and the Fountain Valley High School, California (3-19). A five feet module provides bay sizes from 10'-0" x 30'-0" to 30'-0" x 100'-0".

3.2.2 Module Design and the Size of Classroom Unit

The modern pedagogics demand more new teaching methods and need to consider design and development of more special rooms for new purposes. The classroom unit is still considered the basic element of the school (3-20). According to the general requirements, the classroom is usually divided into three inter-related parts: the class space, the studio for the work of grouping children and the cloakroom. An outdoor classroom is sometimes also necessary (3-21). The size of the classroom unit is determined by the pedagogic requirements and the number of pupils. In recent years, by using the method of floor space per pupil the sizes of rooms can be calculated, and the average number of pupils in the room should not exceed thirty (3-22). The reasons for variation in the size of classroom units from school to school or country to country, is because of differences in building codes, building regulations or the requirements of school buildings.

In some European countries, the specification for classroom space varies from 18 to 22 square feet per pupil, hence, the size of classroom unit varies from 520 to 780 sq. ft. (3-23). For example, the French prefabricated school (Fig.15) uses 1.26 m. (about 4 feet) basic module to give a classroom of 7.40 x 7.68 m. (about 24'x 25') with class space about 630 sq. ft. (3-24). In England, the Secondary School in Workingham has two classroom sizes -- the large one (616 sq. ft.) for more informal teaching and the small one (520 sq. ft.) with formal seating arrangement (3-25). Both of these are based on 3'-4" module. Another

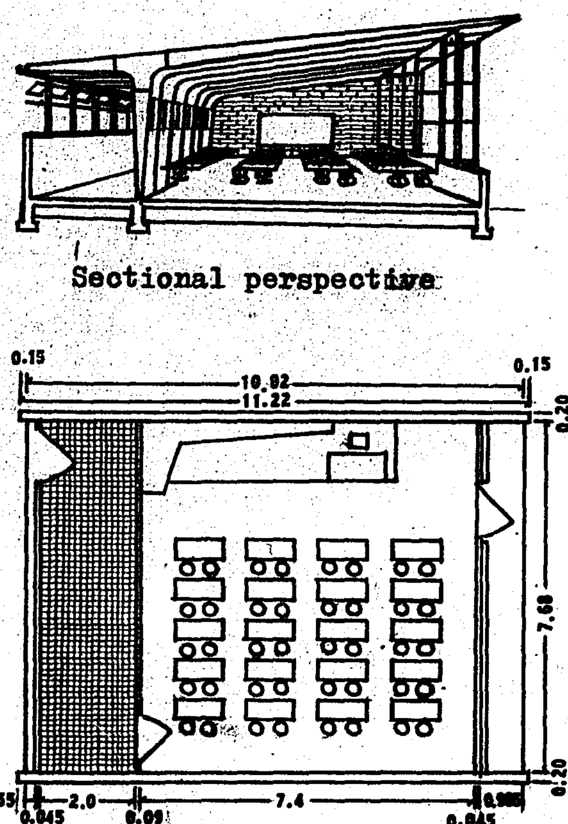
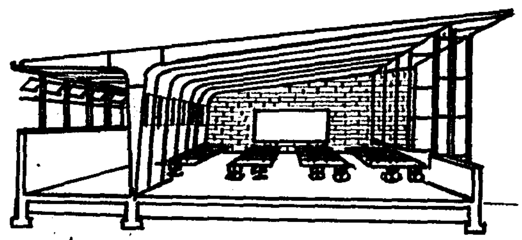


Fig.15. Plan of classroom for 40 children. Infants' School, Martigues, France. Designed by architects: A. Arati, M. Boyer and C. Lestrade



Sectional perspective

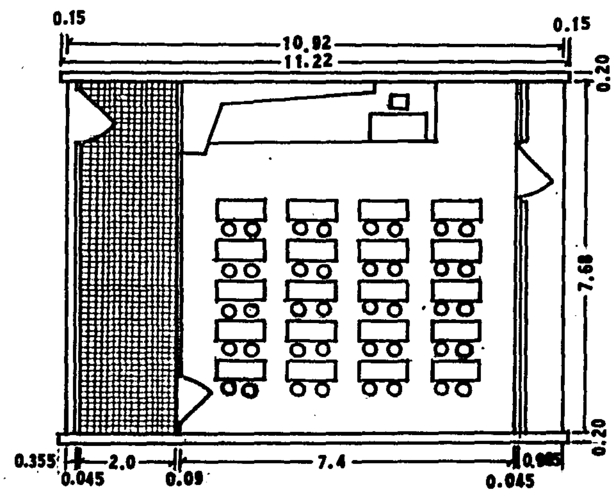


Fig.15. Plan of classroom for 40 children. Infants' School, Martigues, France. Designed by architects: A. Arati, M. Boyer and C. Lestrade

prefabricated Grammar School in Worksop, England, built in 1962 is also based on 3'-4" module with two classroom spaces of 520 sq. ft. and 775 sq. ft.

The standard floor area in Canada varies from 624 to 774 sq. ft. (3-26). The standardization of United States usually ranges from 30 to 35 sq. ft. per pupil. The architect, E. Kump, who has considerable experience in designing schools, recommends 30 sq. ft. per pupil and a standard unit of 30 x 30 x 30, which means a classroom of 30' x 30' for 30 pupils (3-26). Other architects, such as Walter Scholar and Charles Goodman, each designs a double-classroom unit of 2,560 sq. ft. (including entrance porch and glazed corridor)(Fig.16)(3-27), and 2,741 sq. ft. (including open corridor) (Fig.17)(3-28) on an 8 feet bay module system for panelizing.

The differences between American and European school designs are considerable. The differences are caused by a number of factors: the curricula in American classrooms permit wider flexibility, are generally equipped with a projector, television set, etc. and employ additional built-in equipment, such as storage for books, magazines, newspapers etc. The Americans spend more for direct improvement of the classroom, but they build it more simply and reasonably. Similar attempts should be carried out in Europe. The

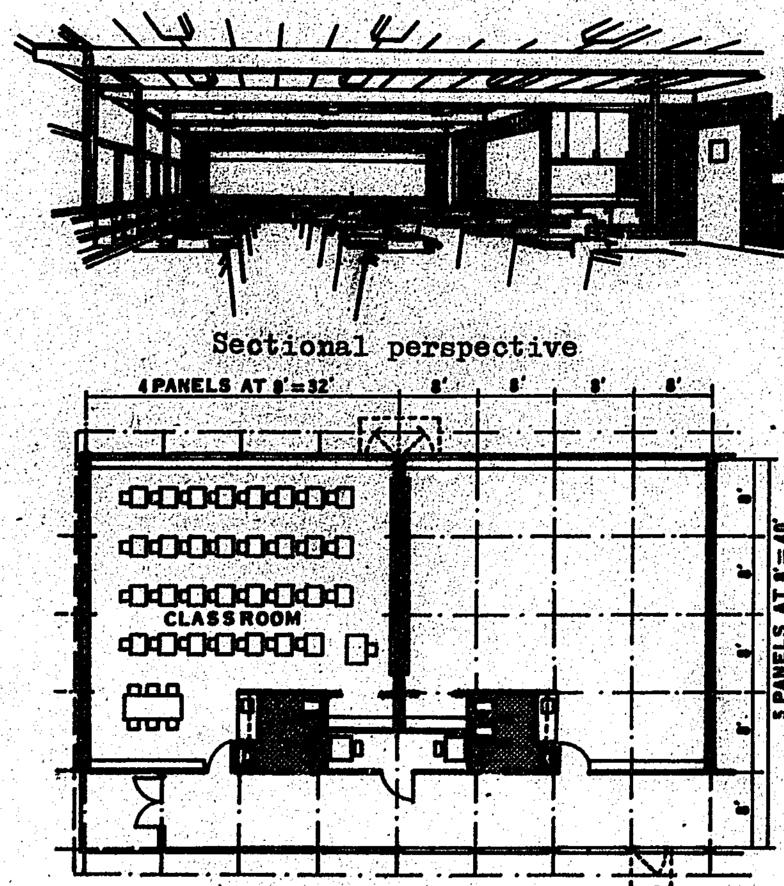
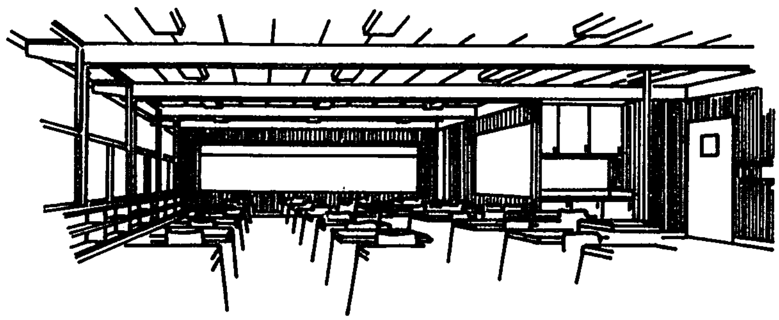


Fig.16. Double Classroom Units.

Designed by Walter Scholer



Sectional perspective

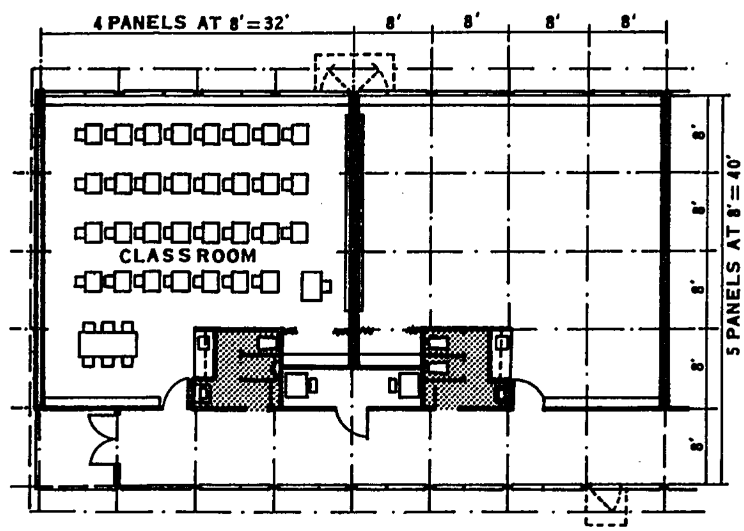


Fig.16. Double Classroom Units.

Designed by Walter Scholer

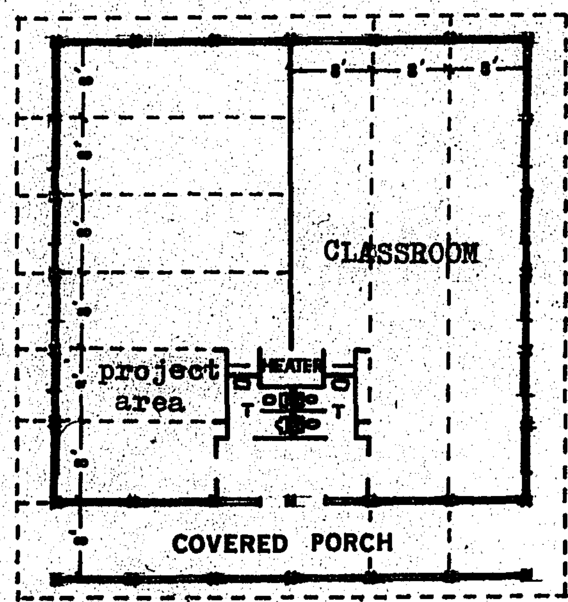


Fig.17. Double Classroom Units.
Designed by Charles Goodman

minimum basic space of 22 sq. ft. per pupil should be enforced in Europe with the American standard of 30 sq. ft. per pupil considered the goal. (3-29).

3.3 Modular Co-ordination

The development of prefabricated building requires a comprehensive range of components with co-ordinated dimensions

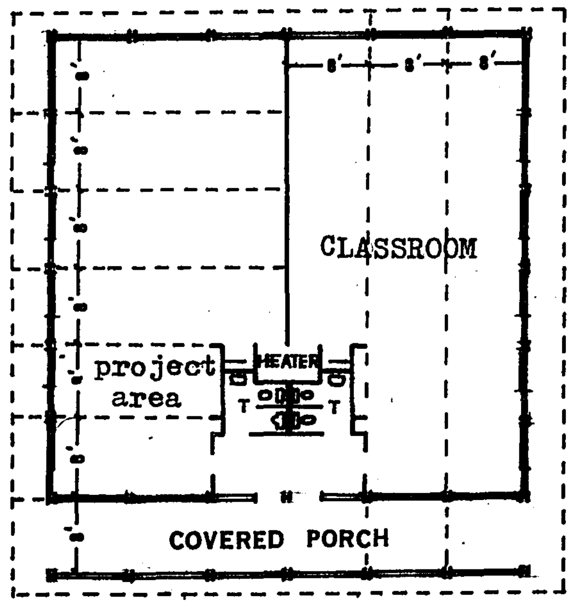


Fig.17. Double Classroom Units.
Designed by Charles Goodman

minimum basic space of 22 sq. ft. per pupil should be enforced in Europe with the American standard of 30 sq. ft. per pupil considered the goal. (3-29).

3.3 Modular Co-ordination

The development of prefabricated building requires a comprehensive range of components with co-ordinated dimensions which can be fitted together (3-30).

The term "modular co-ordination" means the inter-dependent arrangement of dimensions, based on a primary module to provide a new procedure to simplify integrating the size of building components from every single component into a large combination (3-31).

When modular co-ordination is broad in concept, it usually relates to all architectural solutions, including space planning. Buildings can be modulated according to the requirement of the education program. Architectural design and detailing can be modulated during the development of appropriate esthetic and functional solutions to meet the requirement of the educational environment. The types of components and material parts can be modulated to adapt the requirement of building design and construction. However, all elements of modular system should be co-ordinated with one another (3-32).

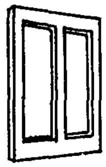
The modular co-ordination used by architects in designing is just a method or system by which an efficiently dimensioned space is achieved. Loss of design freedom or variety of materials is avoided.

3.4 Modular Components

A building consists of "components". The components may be either a single prefabricated unit in construction, or a series of prefabricated units used in the complete building or a functional unit forming part of the building. All of these types are subjected to factory-made standardization (3-33)

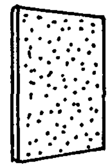
The prefabricated system is based on maximum use of manufactured components (Fig.18) designed for rapid dry assembly on the site. When the basic module has been selected in planning the building, a standard component range with co-ordinate dimension should be chosen in order that different factory-made components can be adjusted together. Take the S C S D system (Fig.19) for example: all components used in this system come from different companies, but these components can be fitted together because the companies use the same basic 5'-0" module(3-34).

Components for outside walls



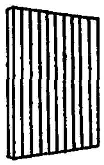
Framing panel

mostly 4' wide



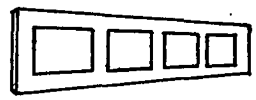
Interior dry wall

mostly 4' x 8'



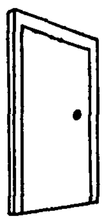
Sheathing panels

mostly 4' x 8'



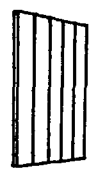
Pre-hung pre-glazed window

600 sizes



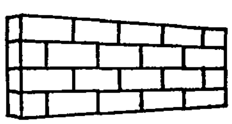
Pre-hung doors

mostly 6'-8" or 7'x36"



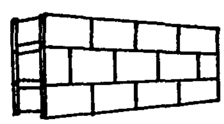
Exterior finish panels

mostly 8' x 32"



Modular brick

mostly $2\frac{1}{2}$" x 4" x 8"



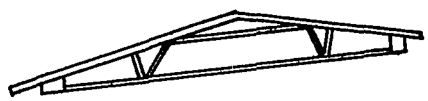
Modular block

Mostly 8"x 8" x 16"

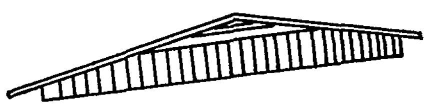
Fig.18. Modular Components.

continued.

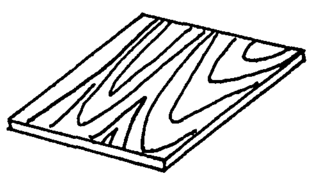
Components for the roof



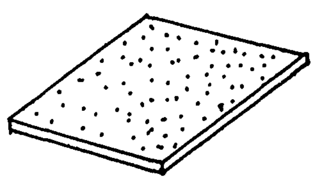
Trusses
mostly 24', 26', 28'
and 32'



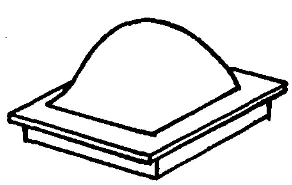
Gable ends
(same length as
trusses)



Plywood sheathing
mostly 4' x 8'



Insulating sheathing
2' x 4' up to 4' x 8'



Sky lights
in many sizes

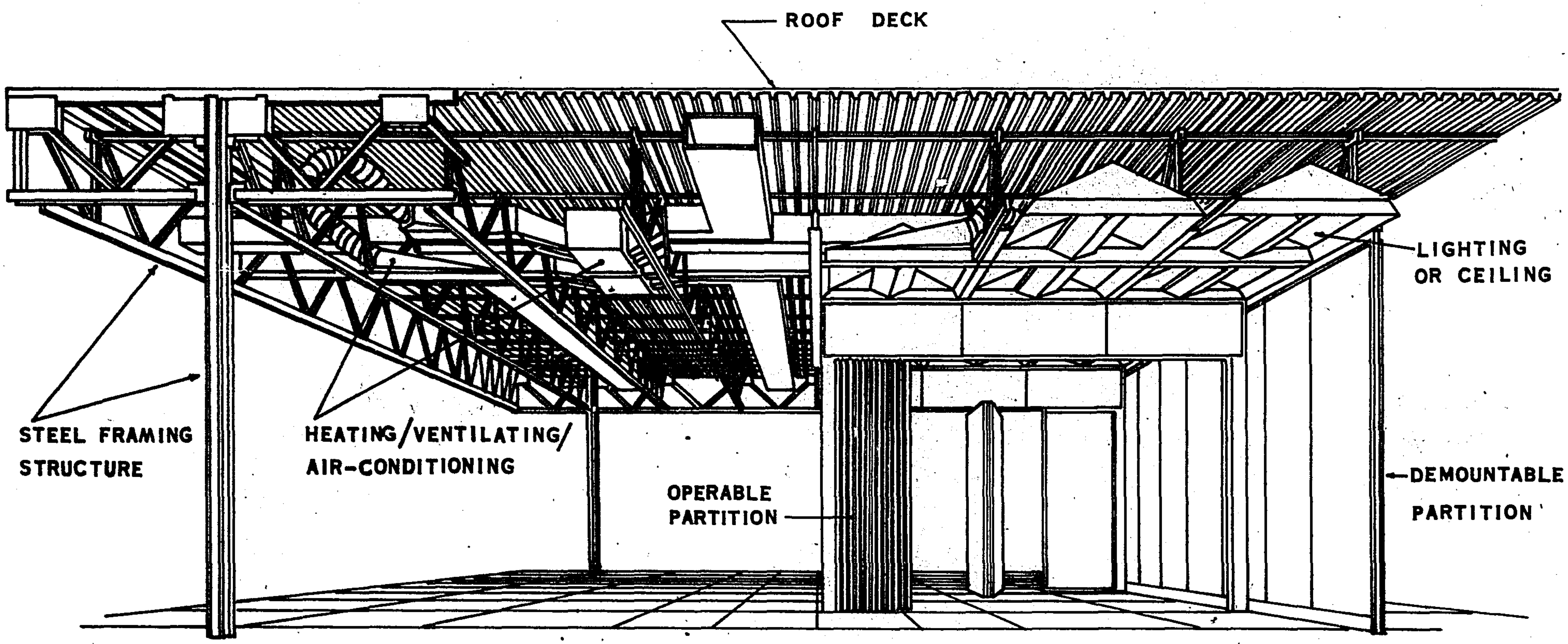


Fig. 19. Major components of S C S D system

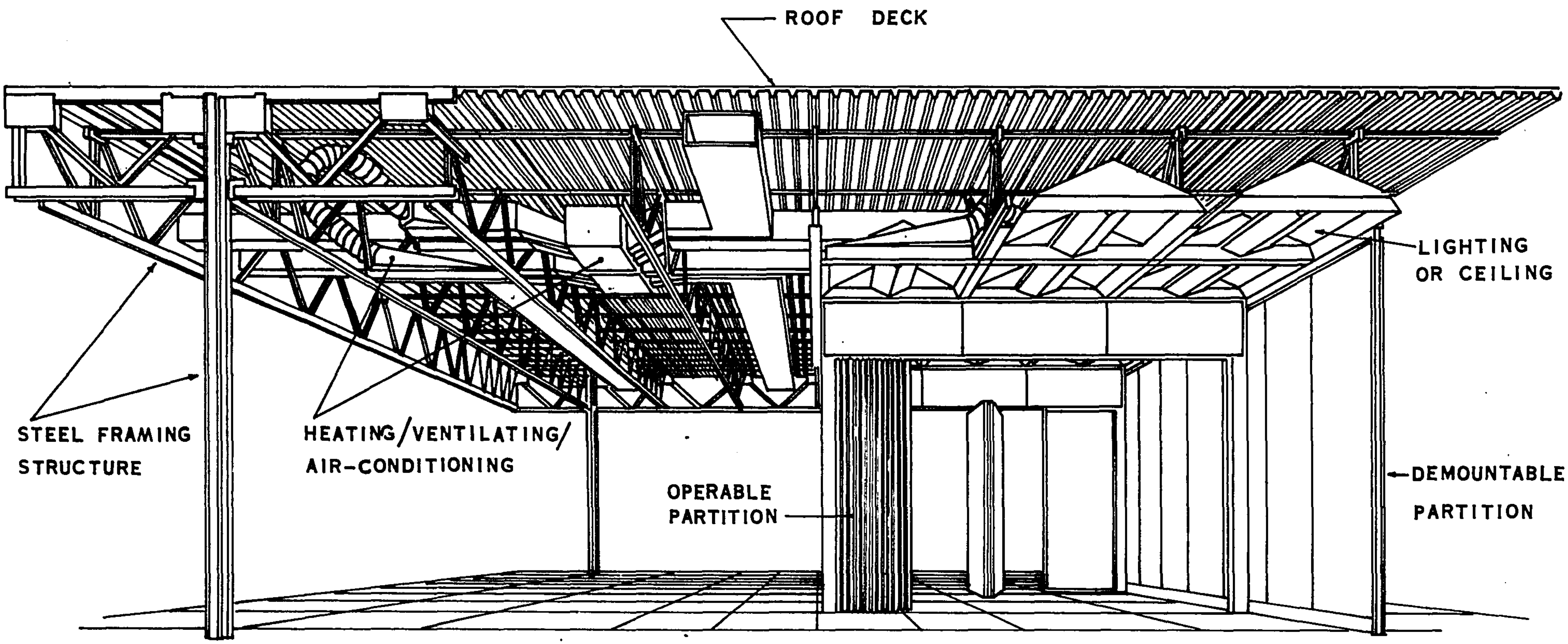


Fig. 19. Major components of S C S D system

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CHAPTER IV page

SCHEMES OF PREFABRICATED SCHOOL

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SCHEMES OF PREFABRICATED SCHOOL

The construction of a prefabricated school is based on the maximum use of factory-made components designed for rapid dry assembly on the site (4-1). It consists of foundations, systems of structure, components of construction and environmental control systems.

4.1 Foundations

In order to design the foundations and to determine the method of prefabricated school building construction, the nature of the soil, the loading capacity, and the effect of weather should be considered. Since the selections of building foundations may be influenced by the type of soil, it is necessary to carry out a detailed survey and to take a soil test (4-2).

Different types of foundations are used for prefabricated school buildings. Strip foundations were used by Homewood Elementary School in Pittsburgh, U.S.A. (4-3). H-beam on concrete piers foundations were used by Newark

Public School in Newark, U.S.A.(4-4) and pile foundations were used by Hertfordshire school building construction in England (4-5). The C L A S P school system in England uses slab foundations (4-6), while concrete block piers foundation are used by Miami prefabricated school construction(4-7) and perimeter concrete foundations are used by Detroit prefabricated school construction (4-8).

As listed above the prefabbricated school building can be placed on various types of foundations. If the school building is not over one story, the foundation should not be a serious problem. If it is over, a soil consultant should be sought before any decision is made.

4.2 Systems of Structure

New construction methods of using conventional materials and new construction materials provide more flexibility in framing design of the building.

Most prefabricated school buildings are constructed today by using light structural frames with light-weight material. The materials of framings are usually steel, wood, aluminum and aluminum alloys or concrete. Since most of these system are developed and are the proprietary of manufacturers, the manufacturers are willing to give full information on their products. The sizes are reasonable and are easy to transport.

4.2.1 Steel Framing

The steel columns and beams are the basic members of any steel-framed structure. The sections of column are either I, H or L shape. The different shapes are connected by different methods. Some are connected by welding(Fig.20) while others by attaching joints(Fig.21). Standardized forms of framed construction have been used. Some manufacturers have developed a suitable system for schools. Take for example, the Hertfordshire School System in England. They used the steel framing based upon 8 ft. 3 in. module recommended by the Wood Committee in earlier school building construction, and later upon 3 ft. 4 in.module recommended by the Technical Working Party (4-9). In the United States, some manufacturers recommended 4 ft. and 8 ft. module (4-10), but later the 5 ft. module was recommended by SCSD system (4-11).

The advantage of using a steel framed structure is not only the ease in construction, but also it provides more freedom in the selection and combination with other marterials.

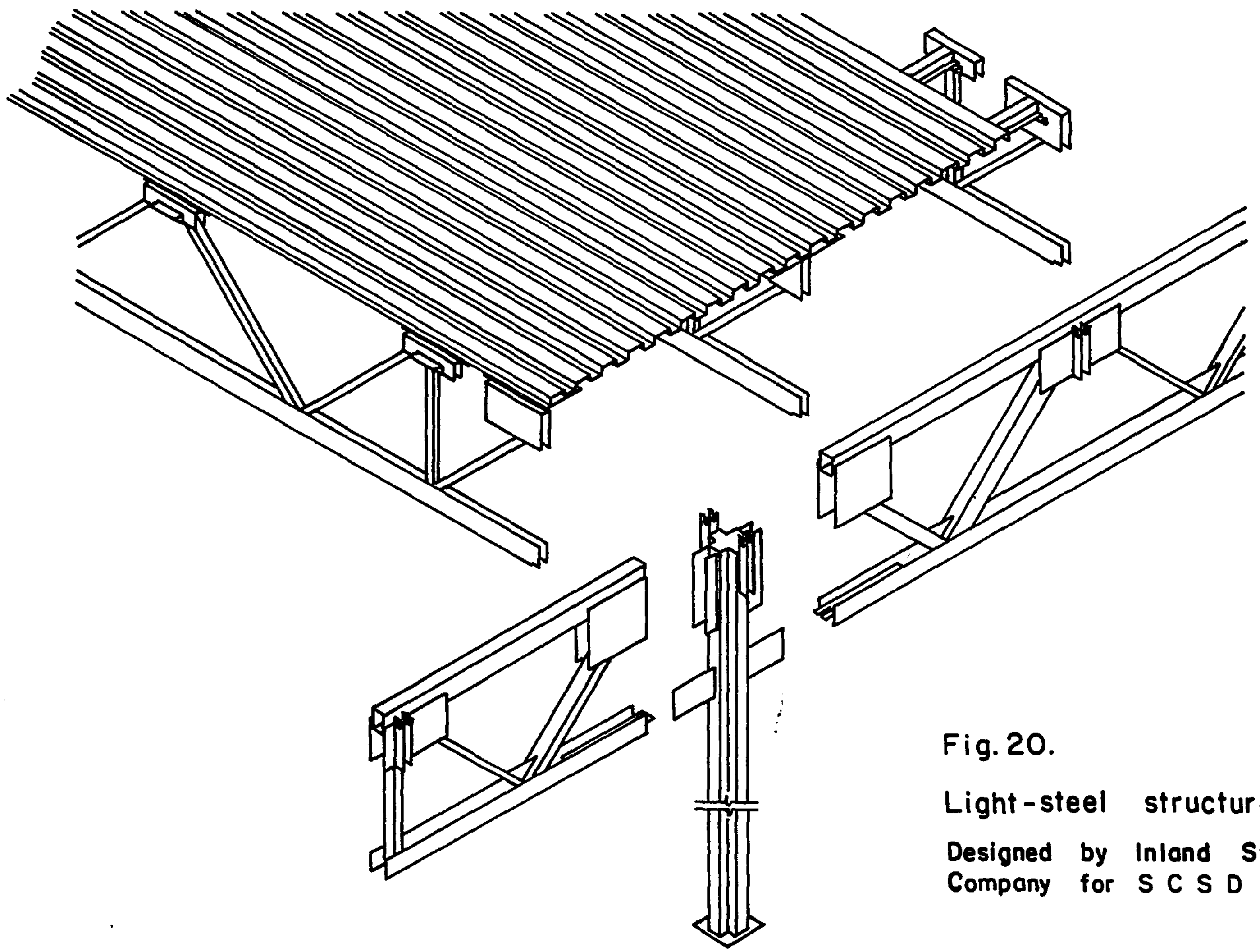


Fig. 20.

Light-steel structural system.

Designed by Inland Steel Products Company for S C S D system.

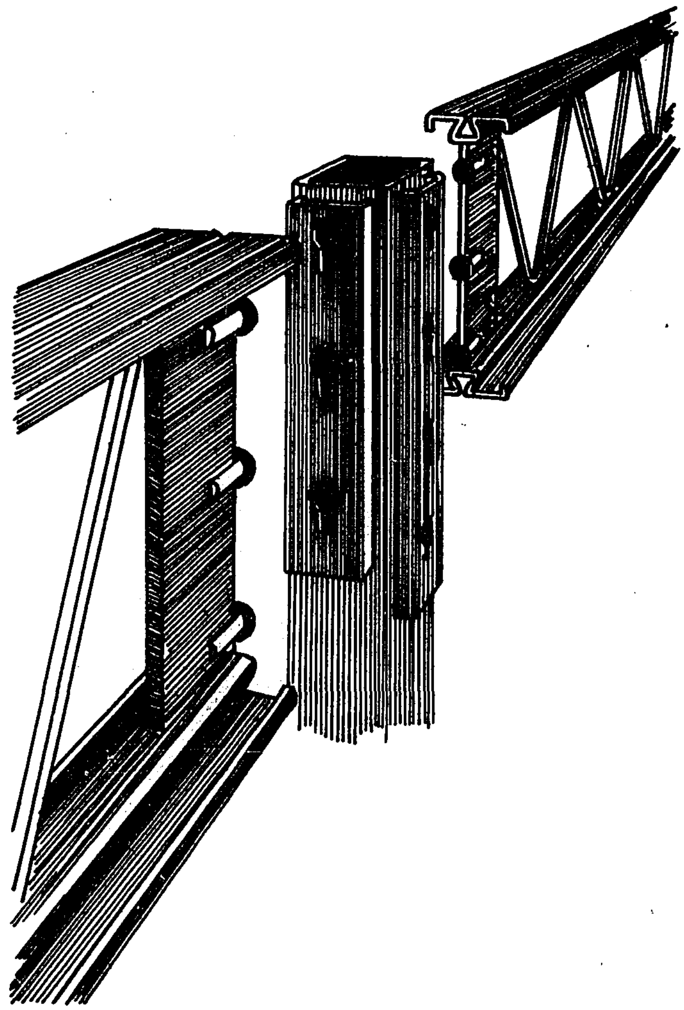


Fig. 21. Method of attaching structural-steel members.

7a

For example, the orthotropic structural system (Fig.20) designed for Inland Steel Products Company by architect Robertson Ward and the engineers Collaborative emphasized ease of shipping, speed of erection, and careful co-ordination with connections which are welded when erection has been completed. All columns are of constant outside dimension and all trusses of from 30' to 75' span have identical geometry; only the gauge of steel changes to provide differing load requirements. To save weight, the steel deck replaces the top chords of the trusses so that the deck is stressed (4-12).

4.2.2. Wood Framing

The present trend in the timber construction of prefabricated school buildings is towards the conservation of timber. The new method is more scientific not only in the use of material, but it also provides better methods of cutting, processing and jointing. The components come from manufacturers in standard sizes, but the construction method differs as each individual manufacturer recommends, such as the Derwent System (Fig.22), England. Because of fire precaution the wood framed structure is recommended

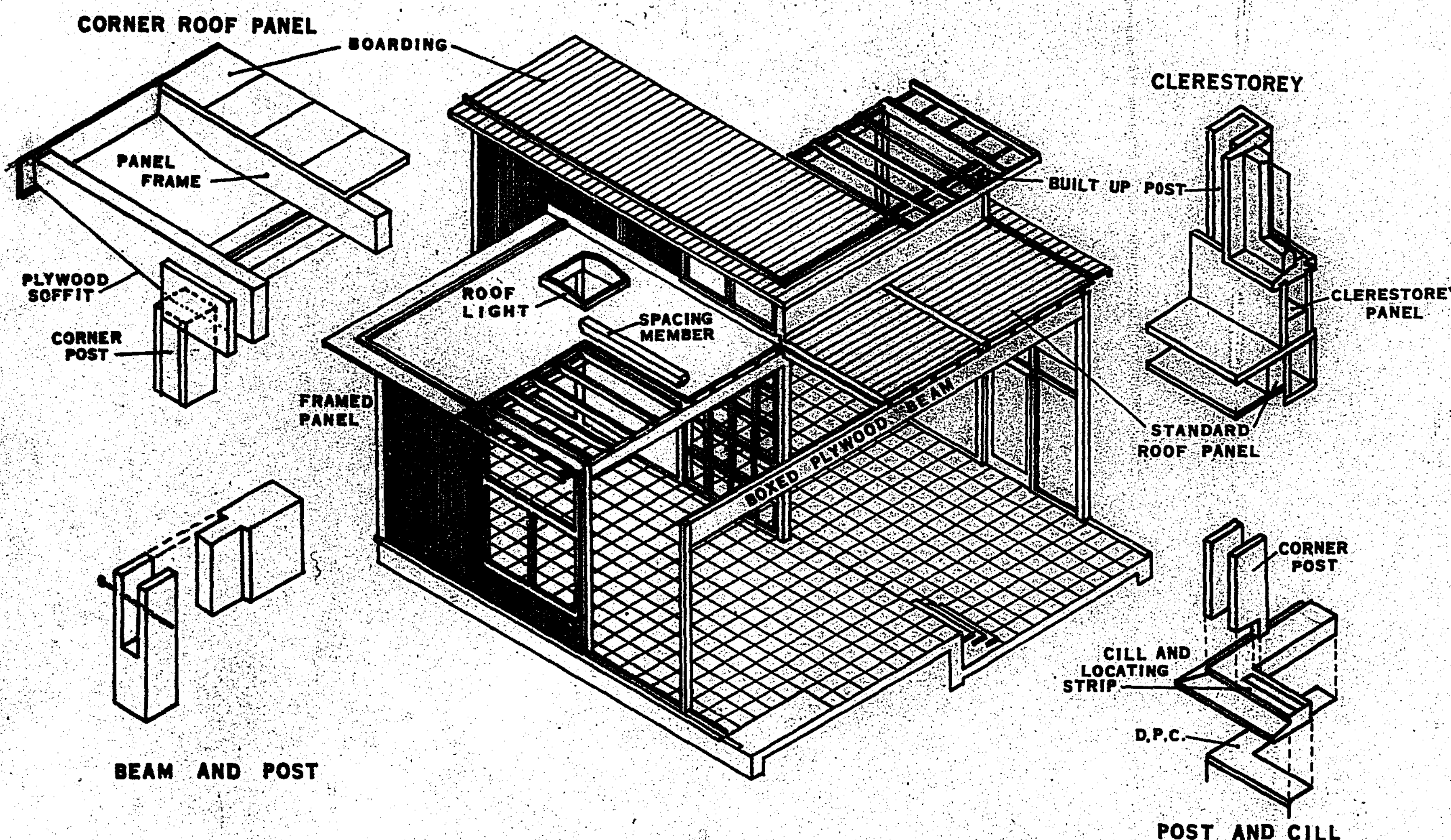


Fig.22. Timber Construction
The Derwent system, England.

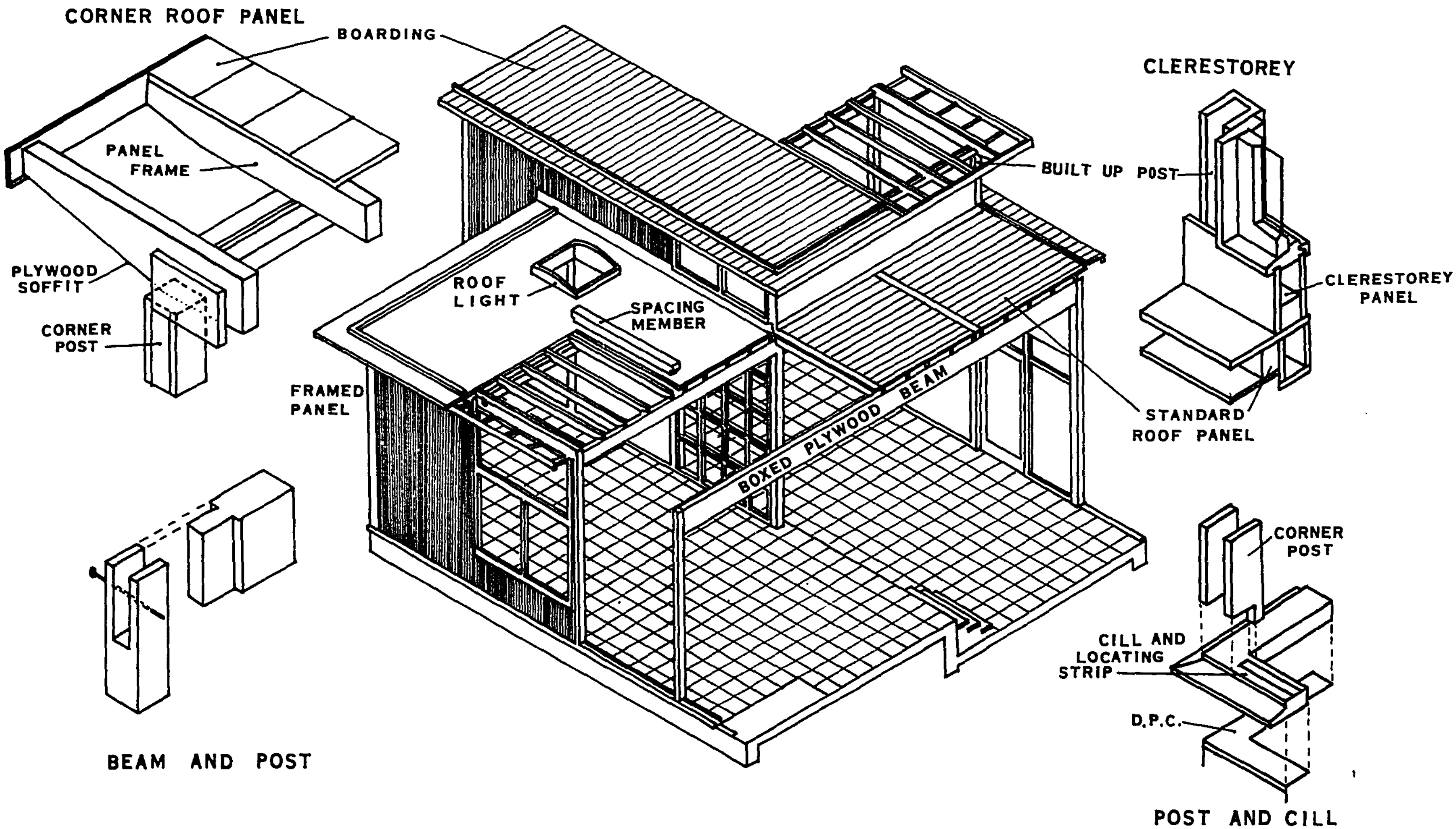


Fig. 22. Timber Construction
The Derwent system, England.

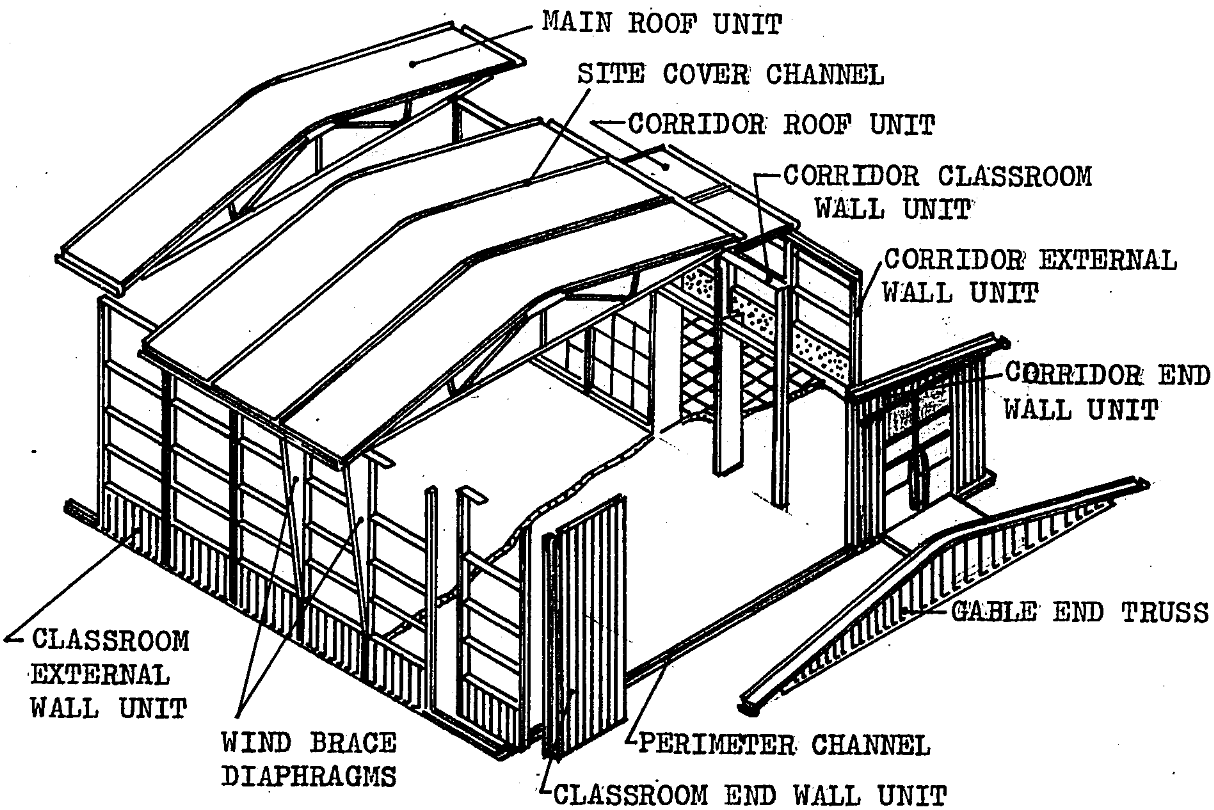


Fig.23. Prefabricated Aluminum School
Lockleaze, Bristol, England.

for school buildings which are not more than one story (4-13).

4.2.3 Aluminum Framing

Aluminum material and its alloys have been widely used as a result of the shortage of other materials during World War II. The advantage of aluminum is its light weight and resistance. There is no other available material which possesses the same characteristics. In comparing steel and aluminum alloys in general structural work, aluminum is more economical than steel (4-14). The complete unit of aluminum alloys for prefabricated school building construction consist of wall and roof which are made by manufacturers, and are ready for bolting up on the site. A number of schools has been built using this system, such as the school at Lockleaze (4-15) (Fig.23), England, designed by the Bristol Aeroplane Company and the school at Martiques (Fig. 15), France (4-16).

4.2.4 Concrete Framing

The use of prefabricated concrete in school construction is economical at the present time. The components of buildings are precast either in manufacturing or in temporary plants on

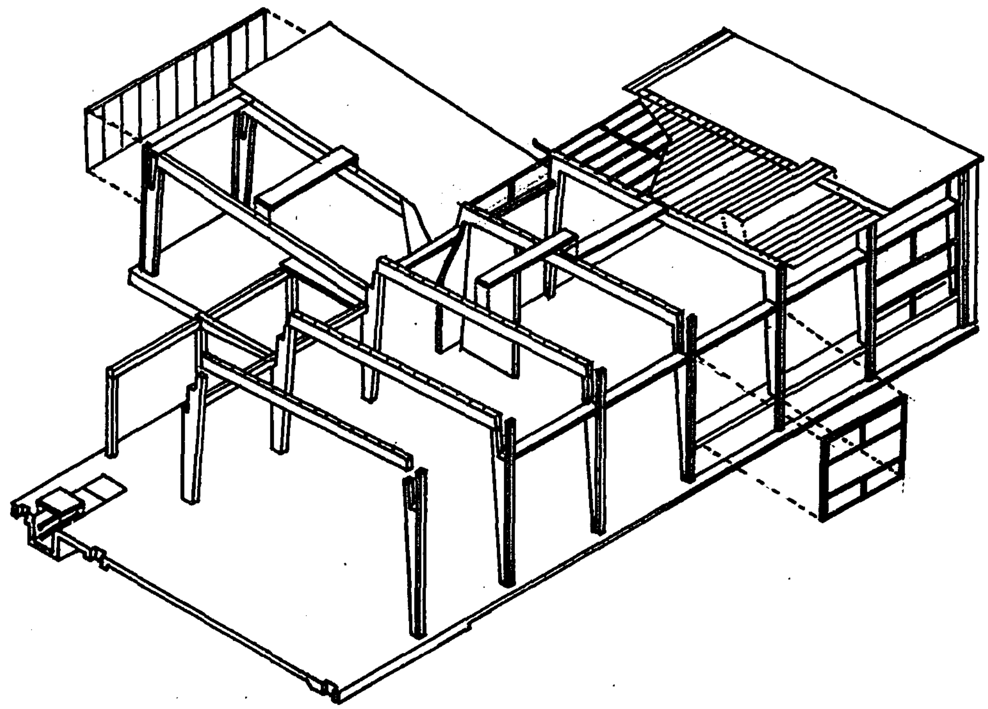


Fig.24. Prefabricated Concrete Construction.
Primary school at Westville Road,
London, England.
Designed by architect Erno Goldfinger.

the site. Manufacturers usually provide a complete detail of technological methods and procedures in order to simplify construction.

Prefabricated concrete system for school construction are frame-precast columns and beams within site concrete joint between columns and beams (4-17). Early examples of such are Worthing Technical High School (4-18) and the school at Westville Road (Fig.24), London, England (4-19)

The greatest advancement in prefabricated concrete system is the development of pre-stressed concrete. The advantage of pre-stressed concrete components is that it reduces the weight of concrete and steel required of the structure (2-20).

4.3 Components of Construction

4.3.1 Walls

Wall panels are constructed of different materials, including asbestos cement, plywood, hard board, aluminum and its alloys, or precast concrete.

The difference between a prefabricated school and a traditional prefabricated building is that the traditional prefabricated building usually uses load-bearing wall as structural walls (4-21), the prefabricated school building uses only movable non-load-bearing walls such as aluminum cladding walls, or precast cladding walls and light weight structure framing in building construction. Movable walls are used not only because of ease of handling, but also because of its flexibility within the building to meet the requirement for future change.

The C L A S P school system in England used precast panel (4-22), and some schools in the Southern California District used insulated wall panels (4-23). But the external walling element was not included in the S C S D school system because the architect-consultants to the school districts required such a wide variety of cladding materials that it would have been uneconomical to include it in the system (2-24). In this case traditional methods of wall construction were used.

4.3.2 Partitions

An important consideration when using partition between schoolrooms is adequate sound insulation. Partitions used in prefabricated schools are divided into three types; fixed,

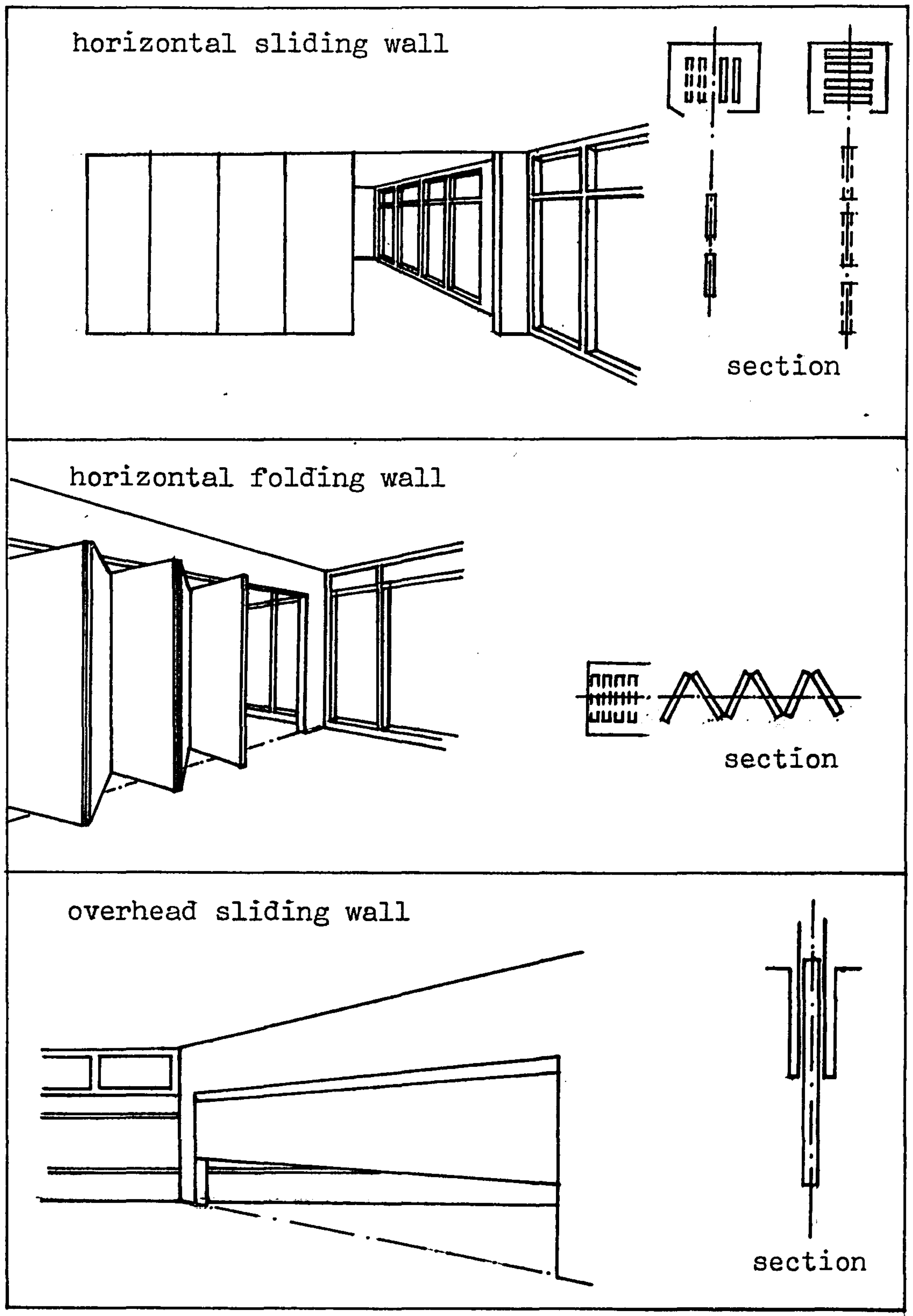
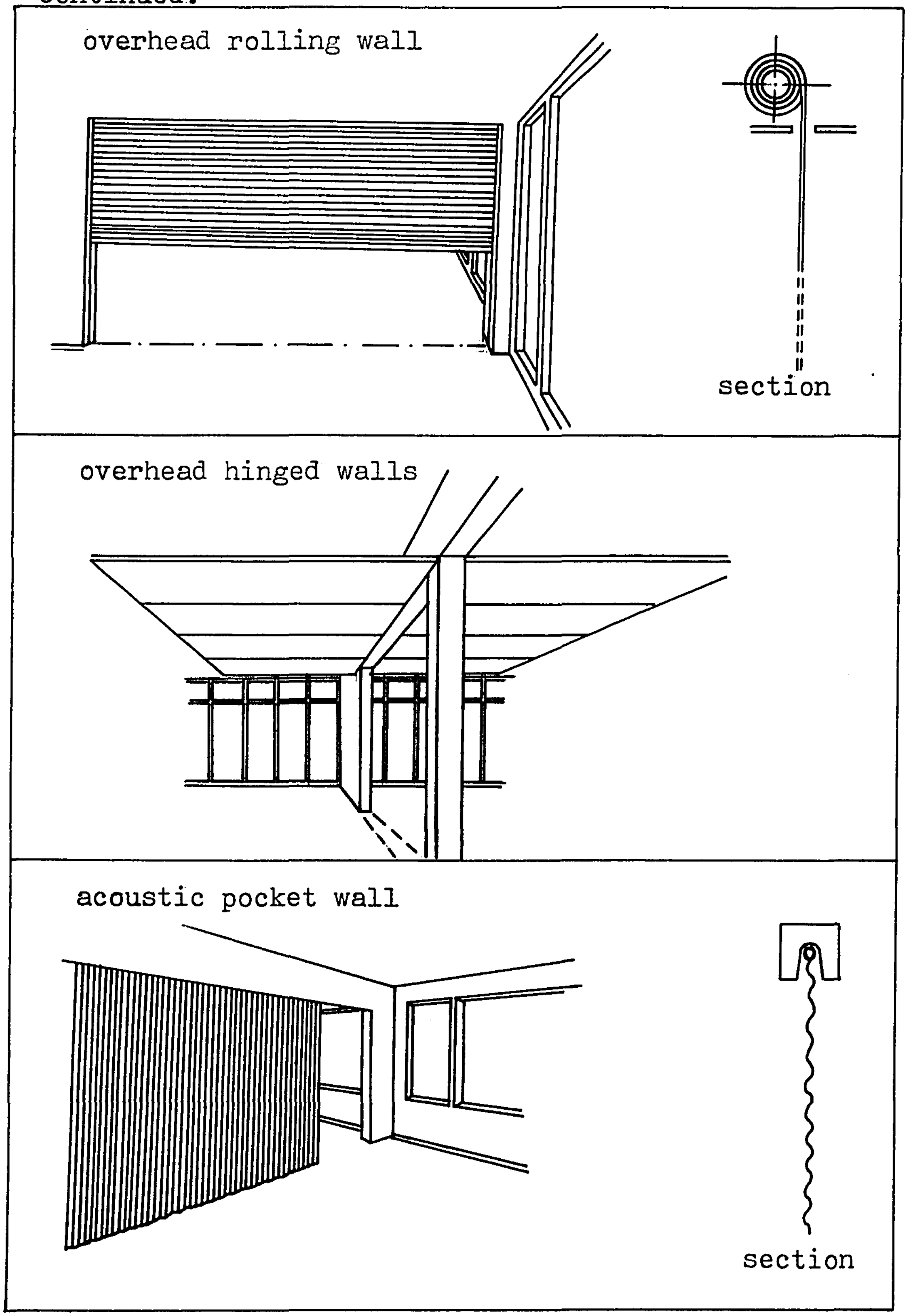


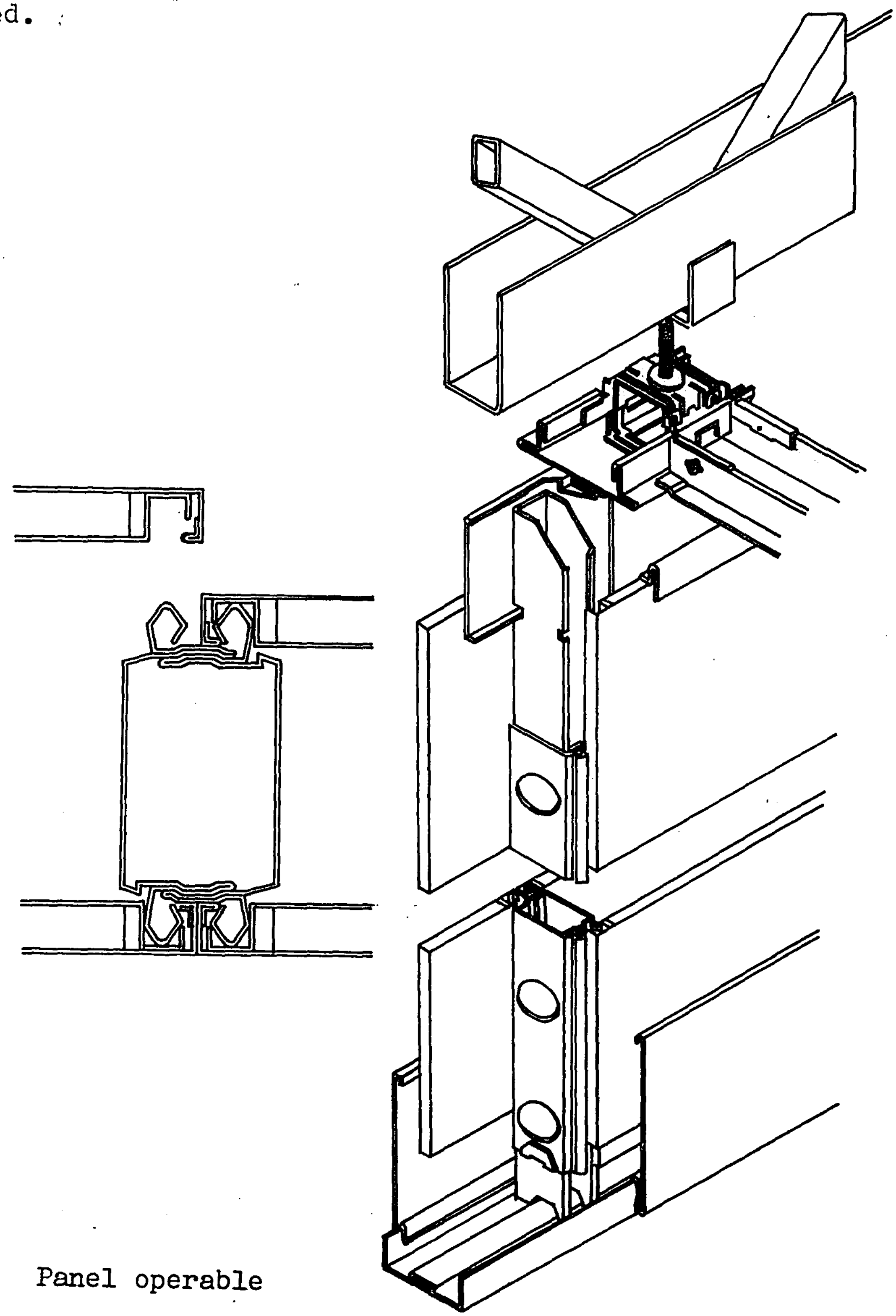
Fig.25. Operable partitions

continued.



Operable partitions

continued.



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Panel operable
partitions.

demountable and operable partitions (Fig.7). The fixed partitions are permanently set in place. Demountable partitions can be moved to a new location to meet the changing requirement with little skill required to re-install. Operable partitions (Fig.25) are normally installed in auditoriums or between classrooms to facilitate a rapid change in the room size, these partitions may be moved at will along their line of placement or removed entirely.

The partitions available from manufacturers are normally made of chalk panel, tack panel, glass panel or back-up panel (4-26). Most partition panels are guaranteed by the manufacturers to have a specified degree of sound insulation.

4.3.3 Floors

The floor system of buildings is dictated by the soil of the site, weather and the kind of building, except when there is a basement. It is more economical when the floor slab can be installed directly on the ground. But when the site conditions are not satisfactory due to the soil, drainage or other similar conditions, a structural floor system should be taken into consideration.

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The prefabricated floor system for school buildings varies with the manufactured products, whether poured concrete joist and precast concrete slab construction, precast concrete joist and concrete slab construction, or steel bar joist and concrete slab construction (4-27). The majority of floor units are designed for easy shipping. For example, the floor beams should be designed in such a manner that they are made in halves which can be spliced together on the site. The flooring panels may be cement asbestos board with flooring tile on it.

For small children the floor spaces should be designed to have a warm surface. Cold flooring can be controlled by the design of foundation walls with a heat distribution tunnel or under-floor heating system.

One of the problems in the design of flooring of school buildings is adequate insulation against impact noise. A satisfactory flooring should provide insulation of both airborne and impact noise (4-28).

The selection of floor finishing is also a difficult problem. The detailed requirements vary for different parts of the school. For those parts used by children, hard wearing qualities are required. In all classroom units the floor should be kept both warm and quiet. The library, requires the greatest sound insulation, while laboratories, kitchens and cookery rooms, the floor finishings should be stain resistant and should prevent accidents caused by fires and spills. At present, many manufacturers recommend asphalt tile as floor finishing for school building. This material possesses durability and is easy to be cleaned. Examples are the school at San Bernardino, California, U.S.A. (4-29). There are other finishes such as the finished rubber floor used by the CLASP school system (4-30), and the carpet floor finishing used by the SCSD system (4-31).

4.3.4. Ceilings

It is most important that the ceiling should provide an efficient sound absorbent surface for acoustic control and noise reduction. In addition, a good light reflecting ceiling increases the illumination of the room.

In school buildings of over one story, the ceiling should be insulated with a reasonable space against airborne and impact noises. The more efficient method is by using acoustic finishing in both ceiling and flooring surfaces. This has been improved by many established schools. In order to get good audio and sound distribution, the ceiling should

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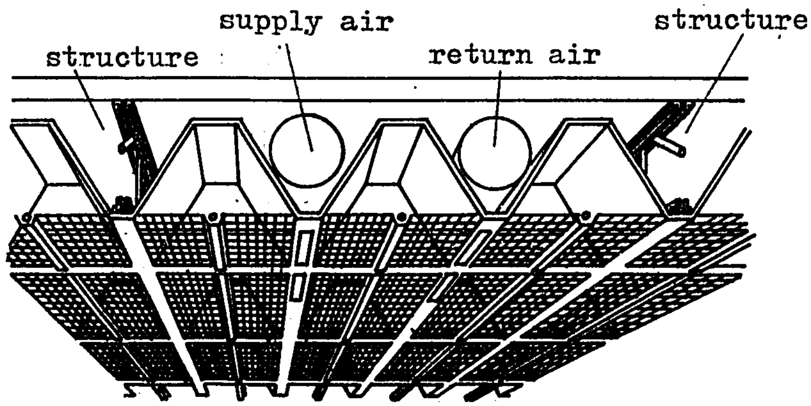
also be designed with sloping surface (4-32).

A wide variety of ceiling materials are used in school construction: acoustic plaster and sprayed-on materials, acoustical tiles fibreboards, acoustical blankets, plaster-board and aluminum materials (4-33). The use of prefabricated ceilings offers easy handling and installation. At the same time it is guaranteed by the manufacturers for its reliability and absorption value in sound insulation.

The early prefabricated school at Bristol, England(4-34) used a fibreboard ceiling. Later a ceiling / lighting "service sandwich" was adopted by the S C S D school system. The research staff of S C S D school system urged manufacturers to design multi-functional integrated components for the ceiling / lighting "service sandwich" (Fig.26). The first method uses a structure which permits duct work to pass beneath it. In the second method, the structure permits duct penetration within the structure depth. The structure forms the duct space in the third method, and it is capable of being penetrated for air distribution and control and for access to the mechanical system. The fourth method is combinations of the above. In addition to the requirements of integration of structure and air distribution, the specifications state that the ceiling sandwich shall provide an acceptable minimum ceiling (4-35).



(1)

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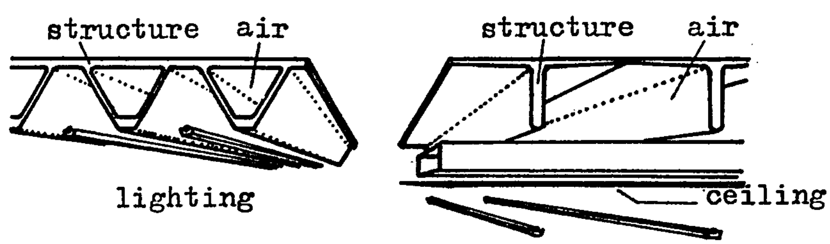
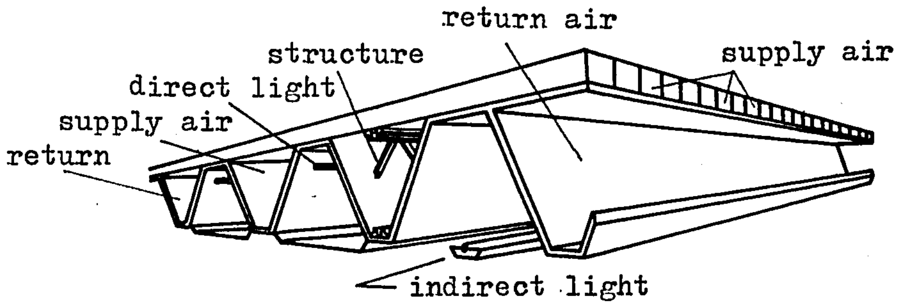


Fig.26. Lighting / ceiling "service sandwich"

continued.



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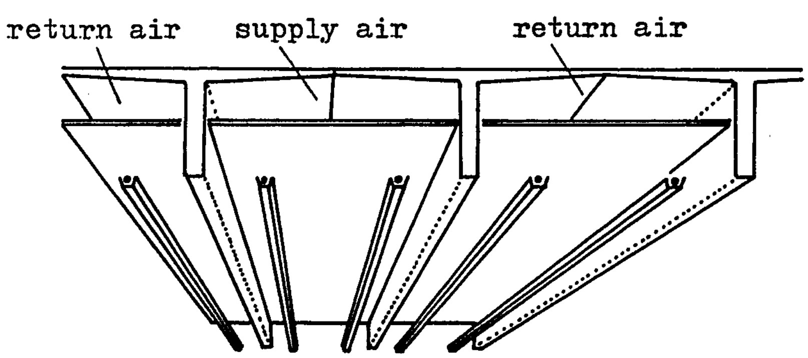


25b

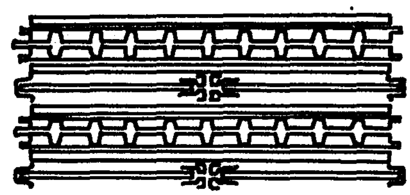
4.3.5 Roofs

An efficient roof should not only keep out rain, snow and wind, but also provide thermal insulation against heat losses.

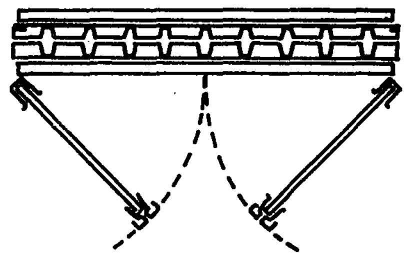
There are two types of roofs - pitched roofs and flat roofs. Both are used in traditional school building construction. The prefabricated school building is usually designed and produced by manufacturers as a part of the building components. For example, the folding roof unit of the S C S D school system in the United States (designed by Inland Steel Products Company) consists of metal roof deck panels and trusses (Fig.27)(4-36). The prefabricated aluminum school in England (Fig.23) consists of roof panels and trusses (4-37). The roof unit of the prefabricated school in France (Fig.15) is made by 'Alufran' aluminum and is ready for installation at the site (4-38). The roof unit of Homewood Elementary School in Pittsburgh (Fig.14) (designed by the United States Steel Corporation) is made of concrete which consists of roof, beam and column (4-39).

As mentioned above, the roof units for prefabricated school buildings differ substantially among individual manufacturers. Most of the manufacturers use light-weight materials

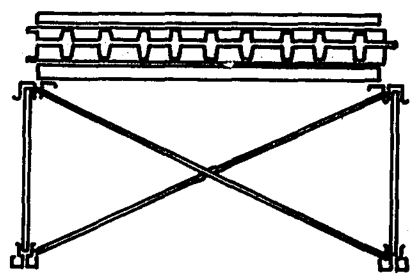
Two truss-deck unit stacked



Truss unfolding



Tension braces in place



Deck unfolding

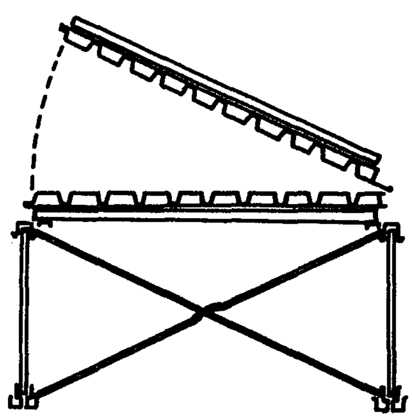


Fig.27. Folding Roof Unit.

in their products, such as steel, aluminum or timber supported by trusses or beams. The material for roof covering generally use asbestos cement sheeting or metal decking or copper which is combined with fibreboard.

4.4 Environmental Control Systems

The environment in every school should promote good health, efficiency and vigorous activities in the children. Prefabricated school systems allow for adjustments and changes to meet these requirements.

4.4.1 Lighting

Adequate classroom lighting is one of the major problems in modern school building. The amount of light is not the only requirement for satisfactory schoolroom lighting, quality of light must also be considered. Windows, clerestory and top-lights must comply with aforementioned conditions in regard to adequate light distribution, reduction of glare, etc. For that reason every source of light must be designed accordingly to allow for control (4-40).

When natural light is inadequate, it is necessary to

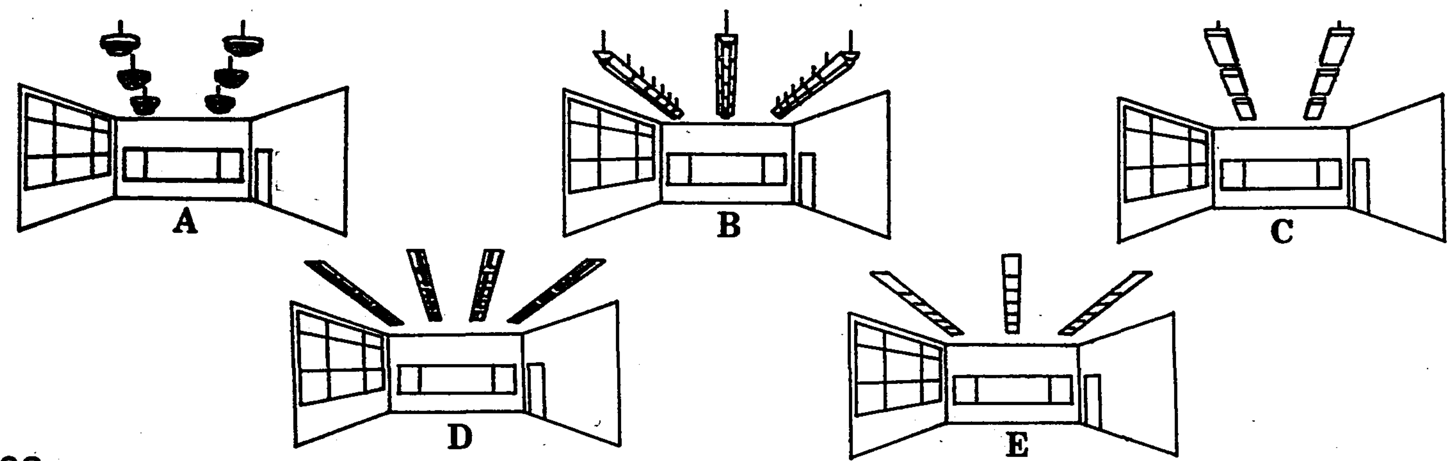


Fig. 28

COMPARATIVE RESULTS OF VARIOUS ELECTRICAL LIGHTING SYSTEMS FOR CLASSROOMS

Description of lighting system				Operating Results			Foot-candles in service
Type of luminaire	Number of units	Lamps per unit	Watts per lamp	Effi-ciency	Main-tenance	Lighting effectiveness	
A Indirect silver bowl incandescent	6	1	500 750	fair fair	good good	excellent excellent	20 30
B Suspended luminous indirect fluorescent	18	2-48in.	40	fair	fair	superior	24
C Suspended direct-indirect fluorescent*	6	4-48in.	40	good	fair	fair-good*	21
D Open flush troffers fluorescent	20	1-60in.	40	good	excellent	fair	31
E Glass bottom flush troffers fluorescent	18	2-48in.	40	good	good	fair	38

* Louver bottom or glass bottom - fair lighting effectiveness with louvered bottom; good, with glass bottom. ** low brightness lamps. Note: all figures for fluorescent lamps exclude auxiliary wattage.

supplement it with artificial light: all classrooms should be equipped with a complete artificial lighting installation. Various electrical lighting system for classrooms are shown in Fig. 28 (4-41).

To design the prefabricated school units with maximum flexibility, the artificial lighting system must be designed or installed to allow future change. Outlets must be numerous to allow alternation of floor plan. They may be installed in the floors or on wall units.

4.4.2 Heating, Ventilating and Air-Conditioning

Earlier prefabricated schools of the C L A S P system used only factory-made parts for the heating system (4-42). Later the S C S D system developed a combination of heating, ventilating and air-conditioning systems for parts of prefabricated school construction (Fig.29). This system is basically a roof-mounted self-contained unitary system of air treating and handling equipment. Each unit serves 3,600 sq. ft. of mechanical service module. The units recirculate from 0 to 67% of the air. The power exhaust fan is also incorporated in the basic unit. Air distribution is through a multi-zoned area incorporating eight mixing boxes,each serving 450 sq. ft.

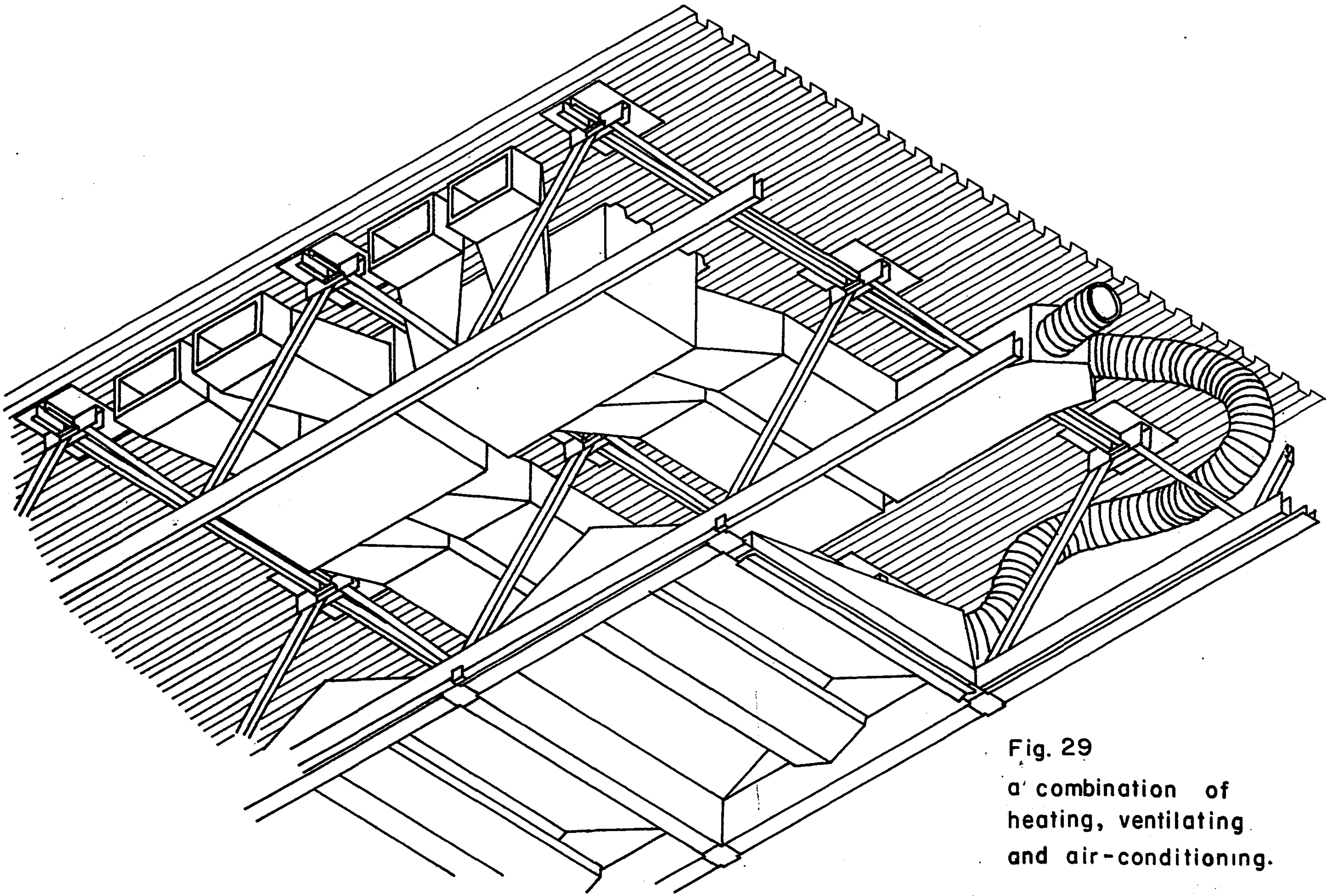


Fig. 29
a combination of
heating, ventilating
and air-conditioning.

of floor space, via fixed and flexible duct work and strip ceiling diffusers. Air return is via strip diffusers into a common plenum space and back into the units (4-43).

This system has a flexible design for all types of space (Fig.9), the air distribution system is simplified in spaces with all-electric control and also automatically dehumidifies the air. It is undoubtedly a good solution for a part of school construction.

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CONCLUSION

Prefabricated systems of school buildings represent a new and important factor in the building industry. They came about as a response to new educational needs and economic pressures. In order to fulfil these needs adequately the systems will have to be studied and developed further.

This thesis discusses only prefabricated systems of school buildings in general. Some examples are selected and described individually with reference to different materials of construction. I hope that my work can be helpful to those people who wish to acquaint themselves with prefabricated school systems. The bibliography at the end of this thesis is intended as a reference index of these systems for more detailed studies.

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