ACKNOWLEDGEMENTS

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

Industrialization of housing construction offers the best solution to the ever growing problem of housing shortages throughout the world. Industrialization, by definition, is the process of converting to the use of building system for large-scale manufacturing off-site. System building includes both industrialization of hardware and a system approach to all aspects of the construction/development process.

The objectives of industrialized housing are:

- to provide the quality and quantity of housing needed by a rapidly expanding population and those badly housed today.

- to provide the flexibility in the dwelling unit to meet the constantly changing need and desires of the consumer.

- to reduce the impact of the seasonality of construction industry.

- to lower the cost through high volume production.

One can purchase a mini calculator for under $20 or an automobile for under $3000. A prototype automobile, however, would probably cost up to $300,000. Today nearly all our buildings are constructed on an almost prototypical basis and this accounts not only for the high cost of building but also for the lack of innovation in the

construction industry.

The Department of Housing and Urban Development in the United States initiated Operation BREAKTHROUGH in May 1969. One of its principle objective was the stimulation of the development of innovative industrialized housing, a concept that was supposed to increase the rate of housing production and thus help to meet the nation's housing needs. In early 1970, out of 601 Housing System proposals, HUD selected 22 winners. Descon/Concordia System was the only foreign (Canadian) proposer to win in the Operation BREAK-THROUGH program.

Analysis and evaluation of all these 22 industrialized housing systems are beyond the scope of this paper. Seven high density industrialized housing systems were selected only. These systems are:

1- Building System International

2- Camci System

3- Componoform System

4- Descon/Concordia System (now Descon System Ltd.)

5- FCE-Dillon System

6- Rouse-Wates System

7- Shelley System

Componoform System could not participate in the Operation BREAKTHROUGH program because of fear of patent infringement by the U.S. government.

Each system was analysed individually and then

evaluated with the aid of Evaluation Matrices technique. These industrialized housing systems are evaluated with respect to their capabilities to satisfy technological and economic performance criteria. The assignment of merit values (ratings) and criteria weight for each criterion was accomplished with the help of architects and engineers who were familiar with the systems.

CHAPTER I

INDUSTRIALIZATION OF HOUSING INDUSTRY

Nearly every contemporary society in the world is facing relentless pressure to do something about improving housing conditions and services, particularly for low-income groups. Since the beginning of the century, many have regarded industrialization of housing industry as the most promising means of solving this problem. If mass production technique applied so successfully to automobiles industry could be applied to housing industry, then our problems could be solved. People failed to realize that with automobiles you do not have to provide the highways — in housing you have to provide the total package — land acquisition through to property management.

This chapter explains the need for housing, history and development, advantages, disadvantages, and economy of industrialized housing.

1.1 Need For Housing

The problem of providing suitable housing in the world, especially those of third world nations is one of critical urgency. The magnitude of the problem of housing in the world could be realized by comparing the world population growth and the number of homeless or inadequately housed people.

The United Nations has made the projection of the
world population for year 2000 a low of 5.7, a meduim of
6.5 and a high of 7.5 billion. It is most important to note
where in the world the largest portion of this increase
will occur.

According to the studies done by the United Nations
the population of undeveloped nations will more than double
during the next three decades while the developed nations
will have a total increase in population of approximately
fifty percent. Figure 1 illustrates the world population
increase and the increase of developed nations compared to
that of third world nations.

The world's need for shelter is at present in the
order of 200 million units, but this number will be increa-
sing at a much faster rate than the population growth,
because of several factors including the lag between supply
and demand, wars and natural disasters and, in particular,
the inadequacy of local government and developers to sus-
tain a sufficiently large market to encourage industrial-
ized production of housing. It has been predicted that by
the end of this century the need for shelter will reach
one billion units.

If we multiply these numbers by the average number
of occupants per unit — the conservative number of 3 — we
find that nearly half the world population will be without
shelter at the end of this century, a great population of
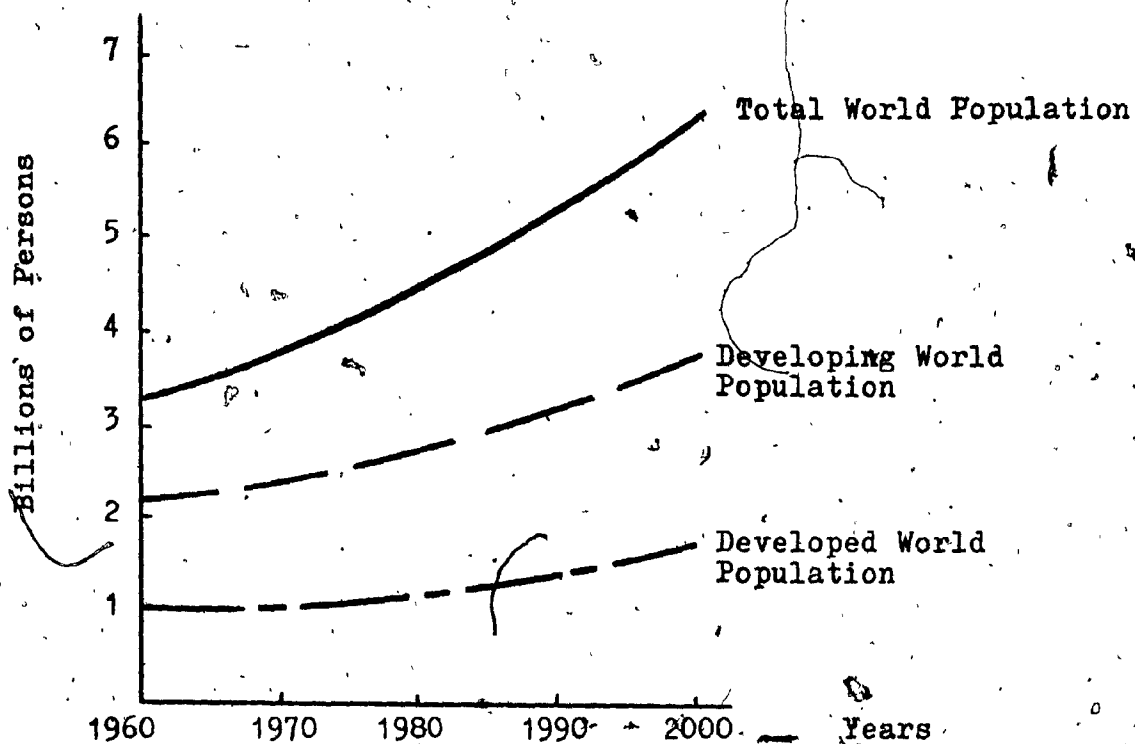
Fig. 1- Projections of Population to Year 2000.
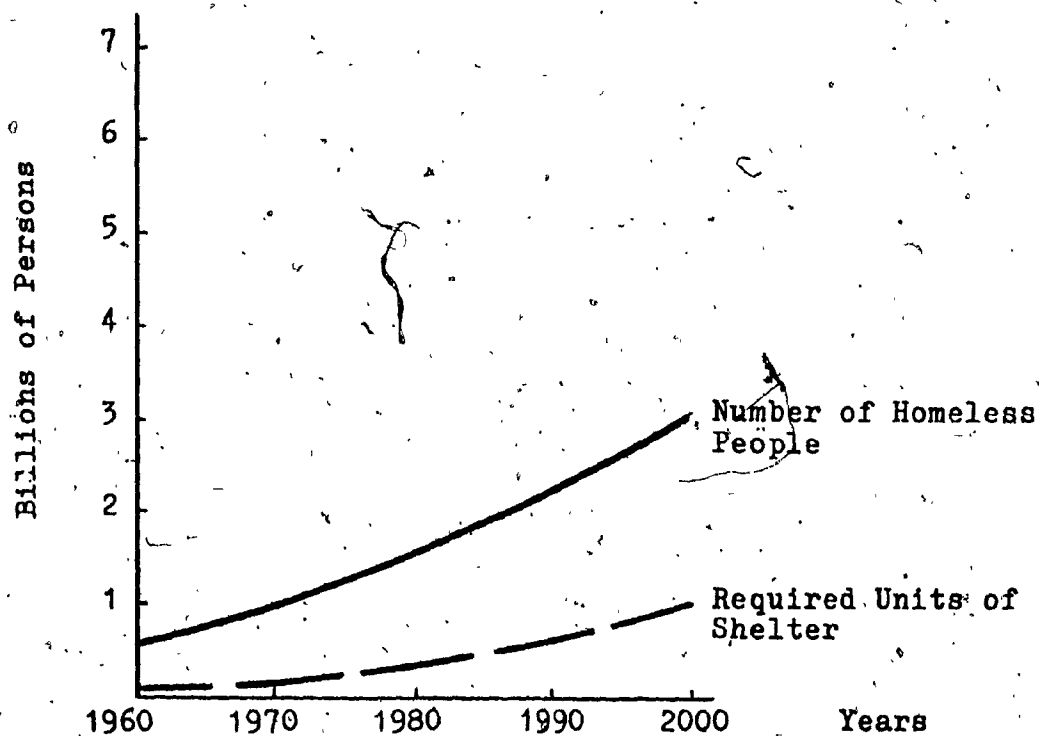
Fig. 2- Projection of Housing Shortage to Year 2000
in Number of Units and Number of Homeless
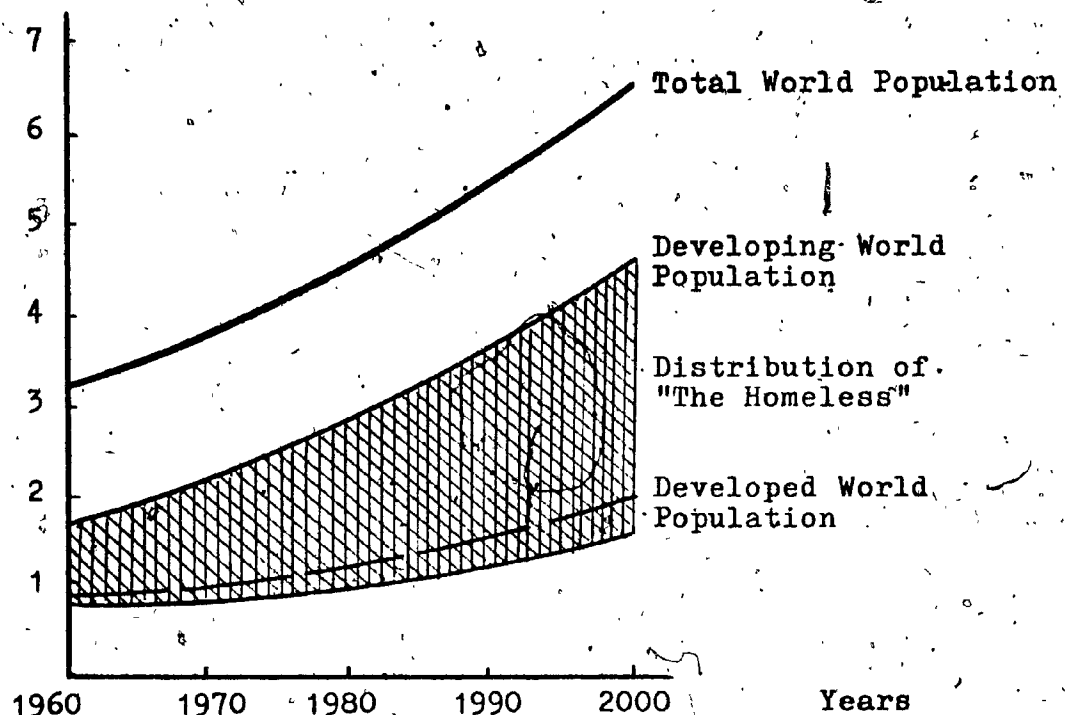
Fig. 3- Distribution of "The Homeless" Over The World Population

Sources:

- United Nations, Department of Economic and Social Affairs; "World Population Prospects As Assessed in 1968", Population Studies No. 53.

  United Nations, Department of Economic and Social Affairs; "Growth of The World's Urban and Rural Population, 1920-2000", N.Y., 1969.

  United Nations, Department of Economic and Social Affairs; "Compendium of Housing Statistics 1971", First Issue, N.Y., 1974.

which is in the developing world. Figure 2 & 3 present the magnitude of this situation in a graphical form.

1.2 History and Development*

The concept of housing prefabrication, particularly in the developed nations, are not new. As early as 1624, the English made use of prefabricated panelized houses of wood for the New World. Around 1638, Swedish Immigrant to North America brought the idea of constructing simple one room dwelling units out of precut logs. Early in this century, Sears Roebuck sold 110,000 mail-order houses, based on precut standardized components, which pioneered many of the assembly line production techniques in use today.

In 1908, Thomas Edison proposed to pour an entire two or three story house of concrete, but this was found impractical and the idea was abandoned.

In 1910, Walter Gropius, founder of the Bauhaus, proposed the "industrialization of housing," recommending "repetitive production of individual parts....made by machine to the same standard dimension and with provision for interchangeability of parts".

Around 1930, with the establishment of Federal

---

* The home manufacturers association, " A Fact Book on Home Manufacturing ", Washington, D.C.

Housing Association (F.H.A.) in the United States, the need for mass volume housing production became evident because of buyers ability to buy homes on terms they could afford. Consequently, the need for prefabrication became imminent in order to reduce the construction cost.

Albert Bemis and Associates of Boston, Massachusetts, carried out an extensive research in this subject and wrote the proposal entitled "Rational Design". Bemis suggest a typical module as the basis for design and develops a method for establishing standard assembly details and a simplified drafting technique in which all dimensions are referred to a modular grid. After his death in 1936, his successors continued his work and organized Modular Service Association to continue research in the field of modular standards. as a result of this effort, the American Standards Association initiated a project for the coordination of dimensions of building materials and equipments. This was a definite benchmark in the evolution toward prefabrication.

However, industrialized housing systems did not account for any significant propotion of residential construction until the post World War II period. Then conditions in Europe literally demanded hundreds of thousands of new units in the war destroyed-cities on an emergency basis. Thus the stage was set for the only large scale implementation of industrialized housing in the world to

date.

In Europe, since about 1955, due to a very high percentage of government-subsidy for housing and provision of aggregated markets, the growth of prefabrication has been particularly rapid. As a result of this, hundreds of industrialized housing systems have been developed.

Now in the United States and Canada, due to the tremendous promotional impact of Operation BREAKTHROUGH program in 1969, and European experience, hundreds of industrialized housing systems have been developed, (but no significant impact has been made on the traditional process for high density residential construction).

1.3 Advantages of Industrialization

Many advantages of industrialization have resulted in the mass production of building components by transferring operations from the building site to the factory. The major principle advantages are:

1. Speed of Construction. Construction time can be reduced by as much as 25 to 50 percent. Sequential building materials delivery to the site speed up construction.

2. Cost Control. Costs can be reduced by as much as 10 to 30 percent in the long run because of savings in time and building materials, and skilled labor. As a result of repetitive pro-

cessing, construction cost can be reduced subs-
tantially, and the initial heavy investment in
plant and equipment is gradually amortized.

3. <u>Production Improvement</u>. Repetitive reproduction
of a design permits greater design input and
thus ensures a better product. Volume purchasing
permits utilization of better product for the
same price.

4. <u>Prediction of Cost</u>. Cost predictability is po-
ssible to a greater degree of accuracy.

5. <u>Quality Control</u>. Higher tolerances, more improved
manufacturing processes, less maintenance and
material waste and greater consistancy of finish
result for industrialized process in the plant.

6. <u>Production Control</u>. Production could be con-
trolled in the plant that would result in mini-
mizing inventories in the factory or on the site.

7. <u>Climate Control</u>. Fabrication can be generally
independent of climatic constraints in the plant.

8. <u>O rganization and Supervision</u>. is more efficient.
More extensive use of unskilled labor is possible
in the factory because of improved supervision
and quality control inherent in the process.
Productivity is high and the risk of accident is
less.

9. <u>Inventory Control</u>. The tighter inventory controls

possible in a factory setting, eliminate the high
rates of theft and vandalism on the site.

10. <u>Advance Purchasing</u>. A major portion of project
can be pre-purchased thus providing fixed commit-
ments for all but site erection costs and other
non-systems items.

11. <u>Management</u>. Less strain is applied to an already
over taxed corp of Middle Management.

12. <u>Inflation Control</u>. Provides one major constraint
to the inordinate inflation spiral of the cons-
truction industry, i.e., reduced site labor as
inordinate construction worker demands.

13. <u>Technology Innovation</u>. Provides a method for
systematic integration of innovative technology
into construction.

14. <u>Mechanization of Construction Process</u>. Provides
an opportunity for the integration of Industry
into the Construction Process.

1.4 <u>Disadvantages of Industrialization</u>

The disadvantages of industrialization generally
are limited to:

— labor acceptance

— need for an aggregated market

Industrialization requires promised market aggregation in
order to be sustained over a long enough period of time to

amortize the large initial capital investment before profit can be reached and economical housing can be produced.

1.5 Economic Considerations

The major factors determining building costs are as follows:

Construction Cost. Construction costs are the most likely to change as a result of industrialization. The two primary components of construction costs are labor and material.

Industrialization most dramatically affects labor input due to automation and mechanization that would result in cost reduction but in most cases negative attributes appear because of labor disputes and union policies.

The proponents of industrialized housing systems promise major savings in materials costs and saving as well as in labor costs. In the best of circumstances that promise may be fulfilled through discounts on volume purchases, and often through vertical control of supply conduits which eliminate middle-man profits and the need to carry huge inventories.

Interim Financing. Industrialization of building will reduce the time of constructions and simultaneously reduce the cost of interim financing.

Nevertheless, shortened construction time is not an advantages without risk; and in the case of labor and

material savings, the risk is greater outside the world's industrially developed countries. The risk factor increase because industrialization fosters a much more critical interdependance among the specialized elements of production — management, labor and machines. Management must assure that the pace of any subtask is predictable and is balanced with the pace of companion tasks, or bottlenecks will occur. Labor bottlenecks can arise from illness, injury, absenteeism, or strikes. And finally equipment contingencies such as breakdowns, lack of spare parts, or losses of power can also cause time — consuming delays wich can trigger rising cost spirals in interim financing as well as all other cost categories.

The Building Systems. The type of building system plays a strategic role in determining costs in many different ways. In "Closed Systems" a single, exclusive design method promotes unified management control over costs, but in "Open Systems" due to interchangeability of components and greater architectural flexibility, they tend to involve some sacrifice in unified management control.

The number of models, the size and type of building and design principles are a relevant costs variables in industrialized building systems.

Technology. The more advanced the applied technology, the lower are the unit costs if promised market aggregation exists. The development of computer controls

have far-reaching cost implications for industrialized building. As a result the economies achieved are substantial.

Market. Promised market aggregation is a crucial factor in mass production, and hence reduction of cost per unit. Without aggregated market industrialization is meaningless.

Organization and Management. One requirement for achieving a low cost product with a highly industrialized technology is unity of organizational control over all the relevant processes. Furthermore, experience suggests strongly that good organization and skilled management are key factors in the success of industrialized building. In other words, the success of industrialized systems are dependant more on organization and skilled management than on the method of prefabrication.

Working Conditions. By transferring operations from the building site to the factory , organized working conditions have become a major factor in promoting higher productivity. Furthermore, the industrialization of building has made possible, the protection against the vagaries of weather by rapid erection of the building components on-site.

Profit and Overhead. The overhead is reduced in accordance with increasing volumes sold, ultimately accounting for increased overall profits.

It should be noticed that because of a high risk

generally involved in industrialization, it is likely that
the producer will attempt to raise profit level (per unit)
if low outputs or sales are expected. Therefore, the extra
profit will then be passed directly to the consumer.

CHAPTER II

CLASSIFICATION OF/BUILDING SYSTEMS

A building system is the application of modern management techniques to coordinate design, manufacturing, site operations, and overall financial and managerial administration into a disciplined method of building in order to meet specific needs. These systems are subdivided into two main categories, i.e., Closed System and Open System.

2.1 Closed System

In this system the majority of components are sized and detailed for use with each other, usually by one manufacturer, and are assembled with strict uniformity of approach for a particular building system. The components of one system are unique to that system and not used with any other system. Moreover, each system has its own method of joining components. The type of this system is limited to Box Systems.

2.1.1 Box Systems. These monolithic units are factory produced and preassembled boxes with a high degree of finish and a minimum amount of required site erection time, primarily for site utility connection. Boxes are designed to permit stacking, the loads being carried by the side

wall or columns along the periphery. Adjoining boxes can be open to each other laterally or vertically to provide variety floor plans and to eliminate the tunnel effect. Some systems propose boxes that are stacking in a checker-board pattern. An example of this system is Shelley System. Figures 4 & 5.

2.2 Open System

In this system the variety of different sub-systems are used together in varying combinations, thus providing flexibility and greater design opportunity. This system requires dimensional coordination in the strictest sense and a degree of liaison between different manufacturers in establishing tolerances, fittings, and joining requirements.

There are so many varieties of open systems that may de subdevided into two categories, i.e., Total Systems (Panels) and Structural Systems (Frames).

2.2.1 <u>Total Systems (Panels)</u>. Total systems are usually large slabs and panels. They are prefabricated in a factory and assembled at the site. In some cases, the components of one manufacturer are incorporated in the subsystem of an another manufacturer, if the two elements are compatible and dimensionally integrative. This system usually incorporate the mechnical, plumbing and electrical subsystems in the casting process thereby eliminating a considerable

amount of field work. They also incorporate exterior
finishes while interiors require only paint to achieve a
finished quality, due to the smooth surface of the steel
formed concrete. An example of this system is Descon/Con-
cordia System, Figure 6.

2.2.2 Structural Systems (Frames). Structural systems
generally constitute the frame parts of the building, such
as beams and columns, prefabricated off-site and assembled
on-site. Into this frames are fitted infill units, such as
walls, partitions, floors, ceilings, and roofs, also
usually prefabricated off-site and assembled on-site to the
structural members. In these types of systems mechanical
and finishes being done conventionally in the field. An
example of this system is Componoform System, Figure 7.
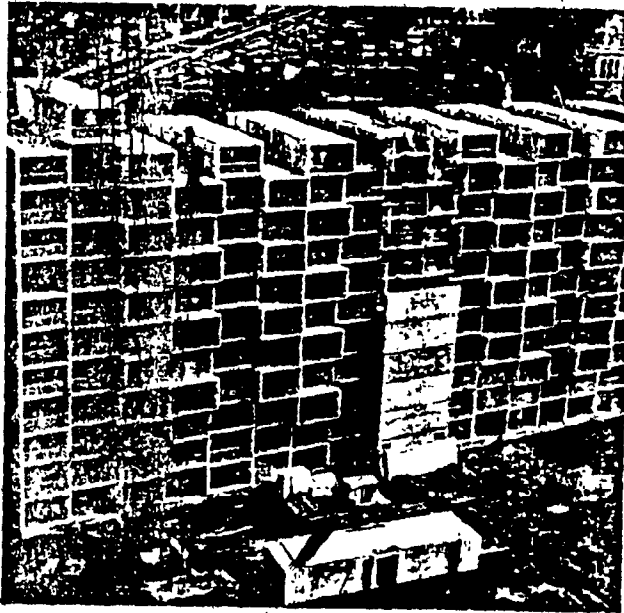
Fig. 4- Closed System; Box
Module. (Ref. 33)
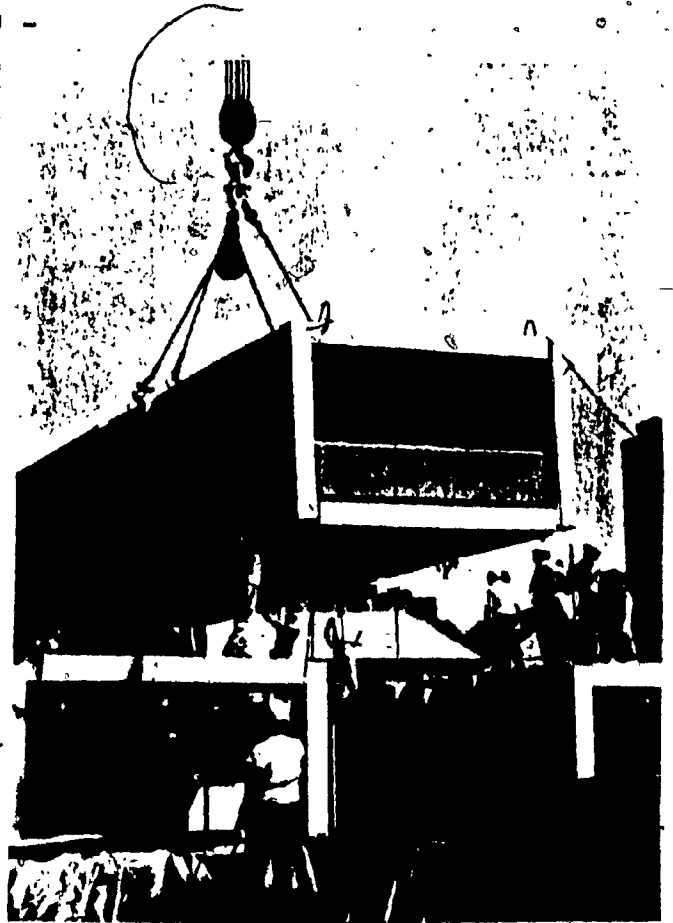
Fig. 5- Closed System; Box-Module.
(Ref. 34)
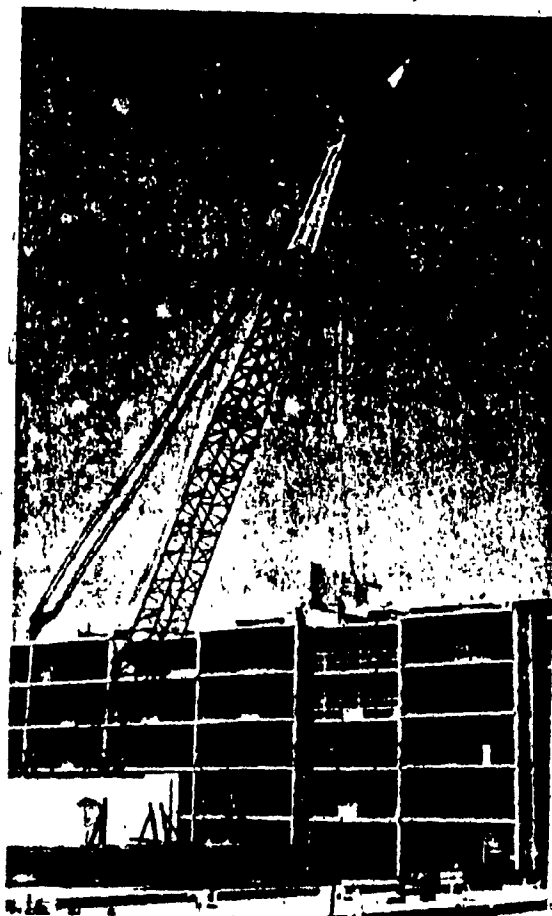
Fig. 6- Open System; Panels.
(Ref. 33)
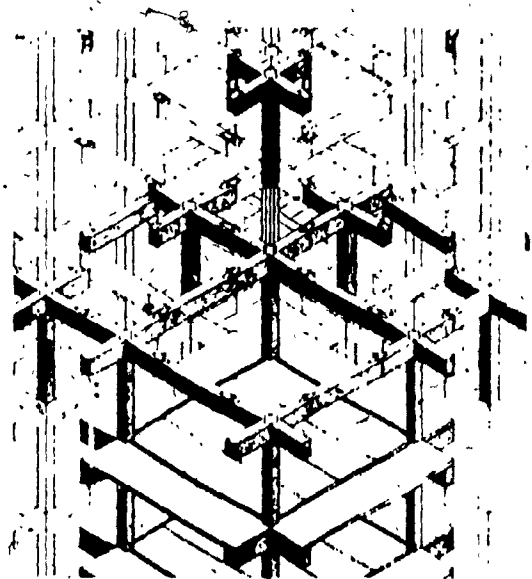
Fig. 7- Open System; Columns
and beams.(Ref. 25)

CHAPTER III

INDUSTRIALIZED HOUSING SYSTEMS STUDIED

The following seven high density industrialized housing systems are selected for analysis and evaluation purposes:

1- Building System International

2- Camci System

3- Componoform System

4- Descon/Concordia System

5- FCE-Dillon System

6- Rouse-Wates System

7- Shelley System

An attempt is made in this chapter to describe and compare all the above mentioned systems.

3.1 Description of The Industrialized Housing Systems

3.1.1 Building System International

1. General. This system is capable of providing all types of housing units from single-family detached to deck house designs and high rise buildings. In the other words, it offers complete design flexibility without restraint as to size of unit, foundation conditions, climatic conditions, variation in profile, exterior and interior finishes.

Concrete is a principle material usage of this system. Precast panels and slabs are produced at the central plant, trucked to the site and assembled. The only on-site work that is contemplated, other than foundation preparation, is the possible casting of the floor slabs if local conditions make this economical. This material can be either an exterior or an interior finish. It is highly resistant to weather, fire and mechanical abrasion. Its density provides good sound resistance and thermal capacity. Figures 8 & 9 show differnt profiles of BSI system.

The panels besides all needed service assemblies, incorporate window and door frames and other required openings. Inside faces of any balcony dividers, public stairwalls, and both exterior and interior panels are finished smoothly.

2. Structure. The basic structural system is a series of load bearing exterior and interior concrete

panels which supported roof and floor slabs to create an integral structure.

Panels were 8 ft high and ranged in length from 8 ft to 30 ft. Most floor slabs were 12 ft by 30 ft.

Generally, the alternate path approach is used to insure that progressive collapse is prevented if critical elements of the primary structural support should fail. In a few situations, alternate load paths are not available so critical members were designed to resist 720 psf without failure. Figure 10.

2.1 <u>Interior Panels</u>. These panels are floor-to-floor height and normally of room length. The thickness of the panel varies according to the structural and acoustical requiements. Interior panels are produced in vertical casting machines and, and with the aid of vibration, a smooth finished surface is obtained.

2.2 <u>Exterior Panels</u>. These panels are made of four layers:

1. <u>Exterior Veneer</u>. Its main function is esthetics. The material can be exposed aggregated, brick, tile, special formed concrete or many other varied finishes.

2. <u>Exterior Layer of Concrete</u>. Its function is to anchor the exterior veneer, to resist water penetration and freezing, to protect the insulation and form a mass for thermal

accumulation which serves to offset the variations of temperature.

3. Insulation. It is usually polystyrene. Its function is to increase the thermal resistance of the panel and prevent condensation. The thichness of insulation is depend upon the required thermal resistance.

4. Interior Layer. This is the structrual layer and includes the reinforcing steel.

2.3 Joints. The wall panels are erected with a 1/2 inch horizontal and vertical spacing between each panel to allow for movement and provide erection tolerance.

Vertical wall panel joints are made by placing a steel connecting bar within the steel loops which project from the panel edges and then filling the joint with grout. Figure 11.

Horizontal wall to floor panel joints are made by tieing together steel loops protruding from the panels with continuous longitudinal steel bar. Prior to grouting the joint, the wall above is leveled with a leveling bolt cast into the lower wall. Figure 12.

In addition to the required roof drain system, this system incorporates "mini - drains" with a view of carrying rain water driven into the joint. Figure 13.

3. Mechanical System. Is designed with regard to thermal features of structure.

3.1 <u>HVAC</u>. Because of the high interia of the con-
crete panels any sudden temperature changes are prevented,
therefore, several method of heating and cooling are prac-
tical and may be installed, depending on the availablity
of various energy sources. These include radiant heating,
gas or electric furnaces in combination with an air condi-
tioning coil and remote condenser, or a combination of
radiant heating system with a package cooling unit.

3.2 <u>Plumbing</u>. Plumbing services are grouped in spe-
cial technical blocks or panels, which are then stocked one
above the other as the building rises to form complete
mechanical service core.

4. <u>Electrical System</u>. Electrical conduit is cast
into the pre-fabricated concrete panels. Flexible raceway
connectors are placed at the panel joints prior to grouting
to join the conduit continuously. The flexible connectors
match the panel setting tolerance. Figures 14 & 15.

5. <u>Kitchen and Bathroom</u>. These subsystems are made
in the factory and shipped to the site for erection.

6. <u>Stairways and Closets</u>. These subsystems are made
in the factory and shipped to the site for erection.

7. <u>Transportation and Erection</u>. In the factory,
concrete panels was transferred from the final assembly
line to the packaging area by using a 20 ton capacity bridge

crane. Three-wheeled dollies (equipped with special saddle brackets to accommodate the 8 ft. by 8 ft. panels) were used to transfer the panels to the storage area. The larger 8 ft. by 30 ft. panels were moved by truck tractor, while the 12 ft. by 30 ft. concrete slabs were moved by bridge crane.

Highway transportation of these panels was accomplished with outfitted-wheel trailers with finger frames which held the panels up right on top of the trailer bed.

Transportation limitation is 100 miles under normal conditions. Lower the limitation is one of economics and logestics and longer distances are possible.

On the site, these concrete panels and slabs were raised into their final position in the hi-rise structure by crane with lifting capacities of up to 125 tons.

Fig. 8- A profile of B.S.I. System.
(Ref. 34)
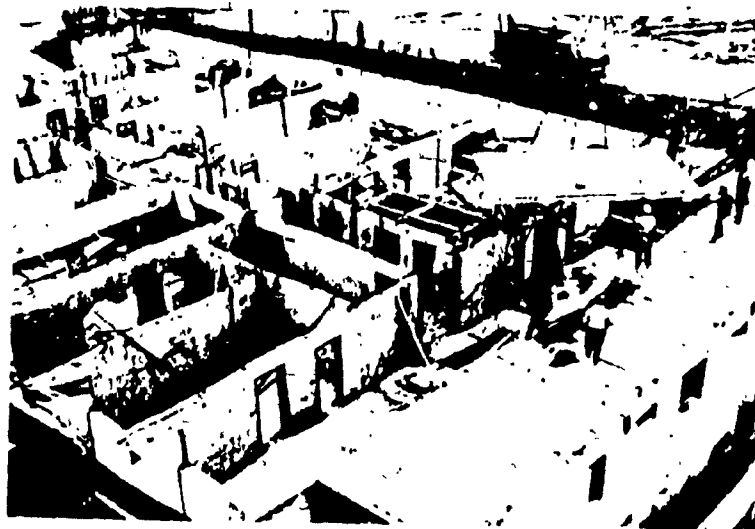
Fig. 9- Ceiling/Floor slabs being placed on wall panels. (Ref. 33)
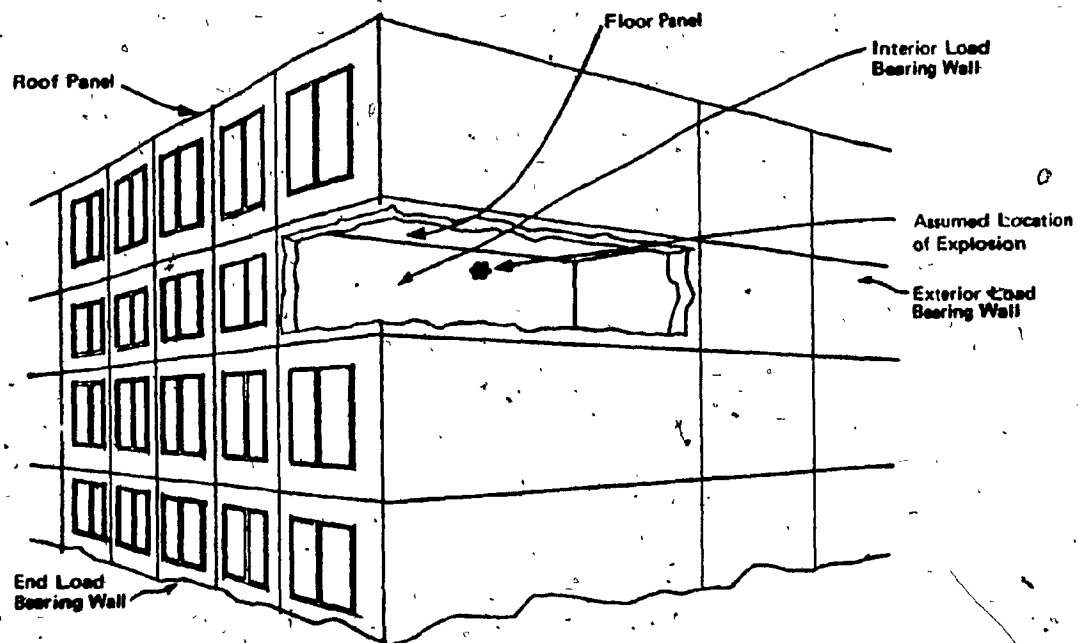
Fig. 10- B.S.I.- Corner panels removed by abnormal loading. (Ref. 32)
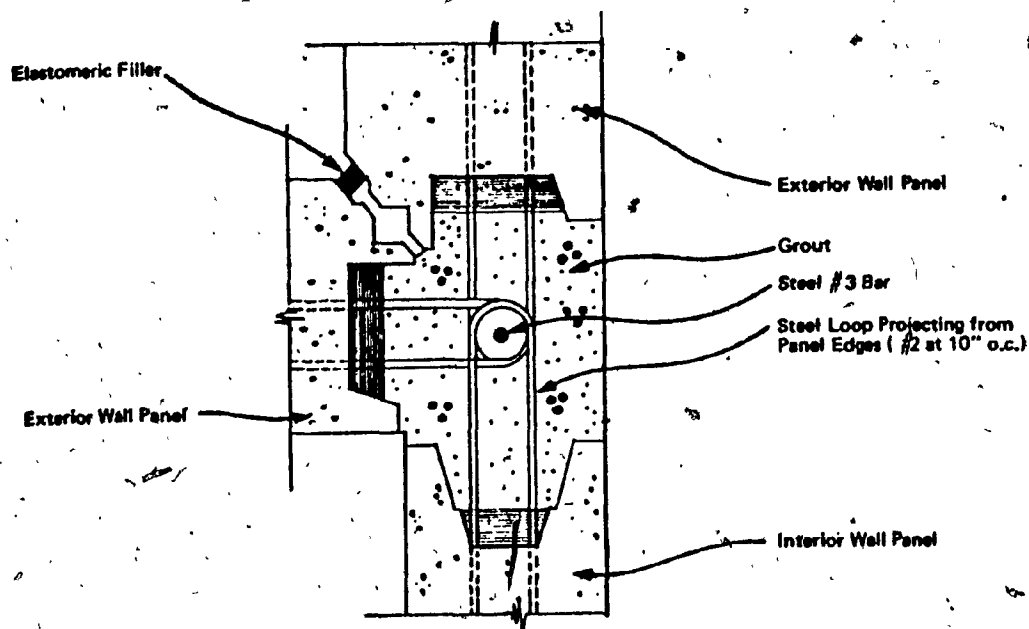
Fig. 11- B.S.I.; Vertical Exterior Wall Joint
(Ref. 32)
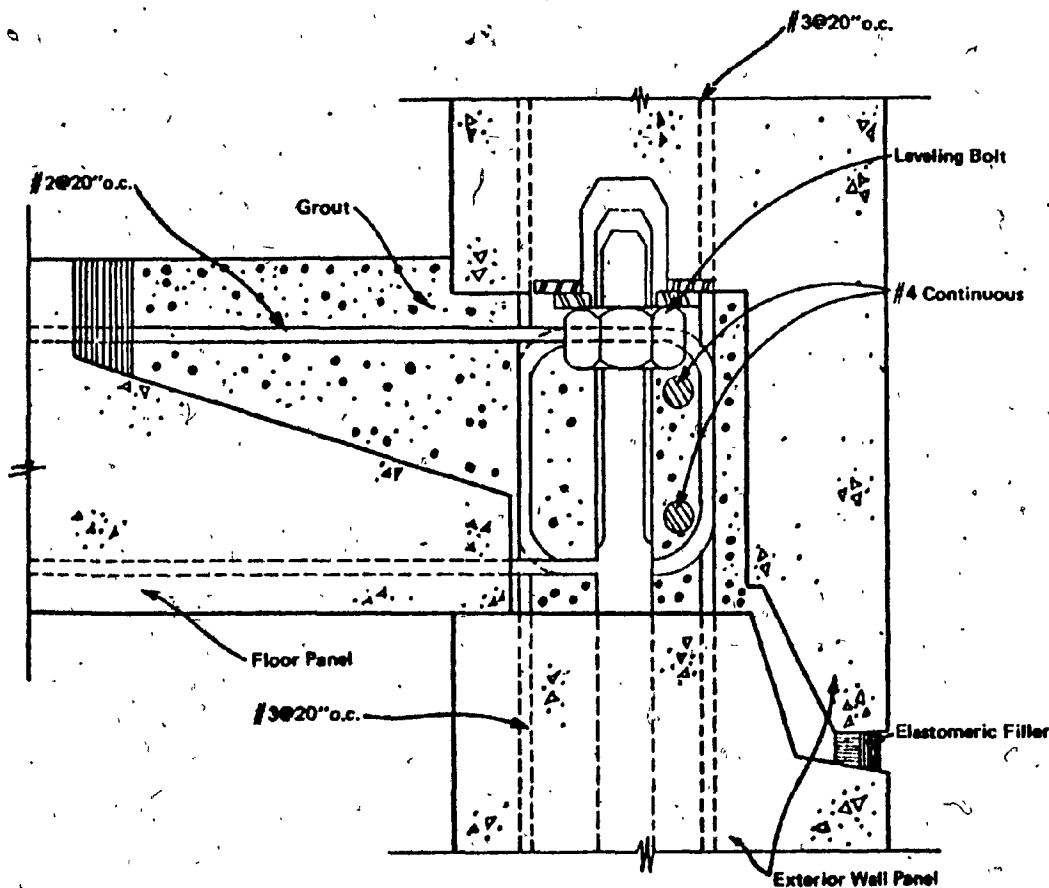
Fig. 12- B.S.I.; Exterior Wall to Wall Joint
(Ref. 32)
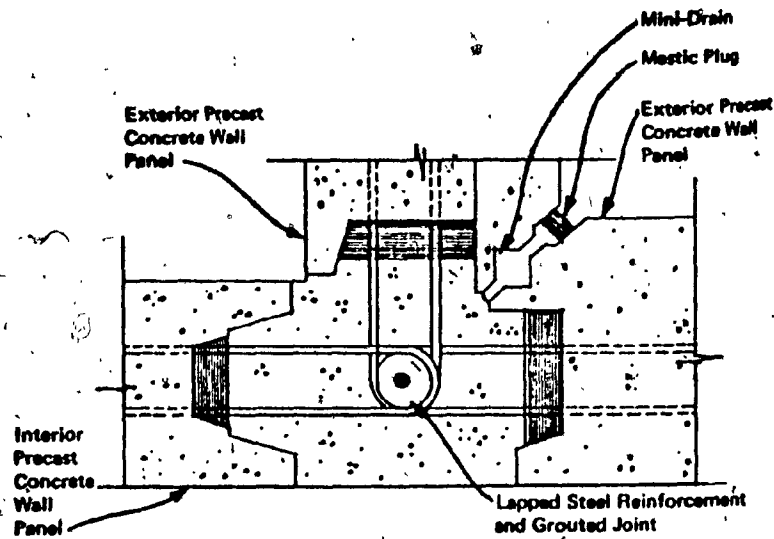
Fig. 13- B.S.I.; Mini-Drain at Vertical
Wall Panel Joint (Ref. 32)
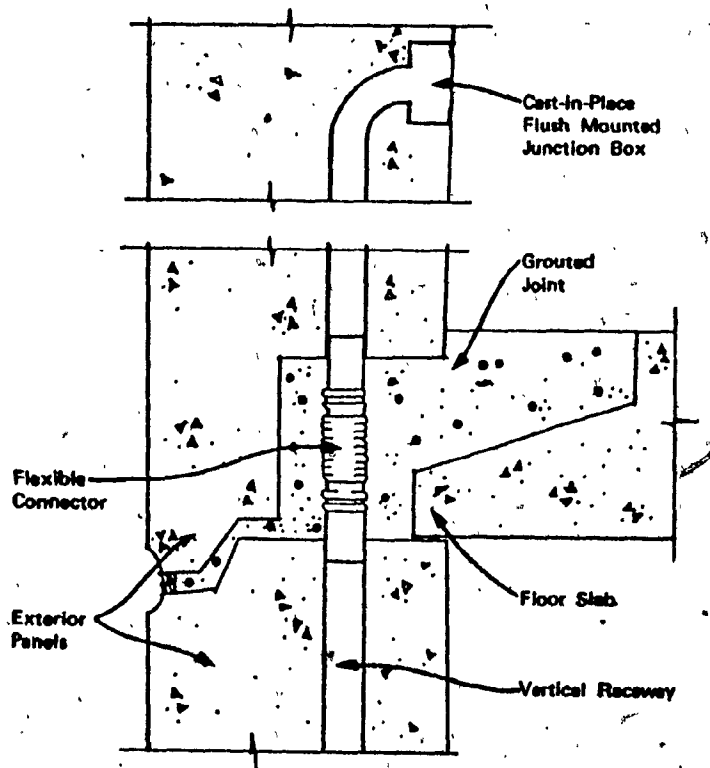
Fig. 14- Typical Straight Run
Connector (Ref. 32)
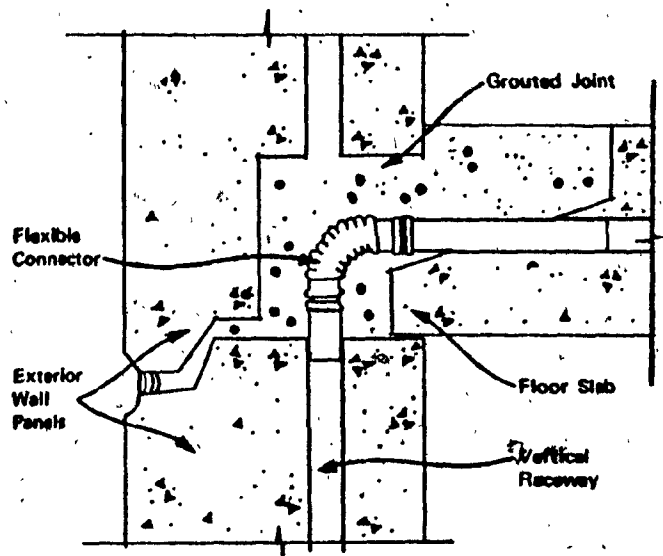
Fig. 15- Typical Elbow Connector
(Ref. 32)

3.1.2 Camci System

1. General. This system has been adapted from French Tracoba No. 1 prefabrication method that has been proved in Europe. The system provides wide architectural variety and is suitable for multi-family, meduim-rise and high-rise. The number of bedroom ranges are from zero, in efficiency to six bedrooms.

The system is completely adaptable to all codes, climatic, topographic, seismic and soil conditions. Density range is limited only by local zoning codes. Figure 16, shows a profile of Camci System.

Main elements are load-bearing cross walls, floor panels, roof panels, elevator shafts, facade walls, gable walls, and stair-ways. Window, doors, piping, electrical conduits and other features can be incorporated in the panels at the plant.

One of the time-saving, novel component of this concrete panel system is the quickly attached, precast concrete balcony, Figure 17. The shape of the balcony module can be varied giving the architect the opportunity to design a range of economical and pleasant building facades.

2. Structure. The structure of this system consists of precast reinforced concrete wall and floor panels. Wall panels ranged in length from 22 ft 11-1/4 inches

25 ft 6 inches, and in width from 8 ft 7/8 inch to 9 ft 2-1/4 inches. Typical floor slabs were 25 ft 1 inch by 12 ft 1 inch. Panels and floor slabs were approximately 6 inches thick.

The alternate path method is used to show compliance with the progressive collapse criterion. Vertical joints between wall panels and horizontal joints between wall and floor panels tied by reinforcement and grout to provide structural continuity. The structure is designed to bridge openings caused by failure of a corner end wall panel as illustrated in Figure 18, any other wall panel or other elements of the primary structural support system.

2.1 <u>Interior Panels</u>. most of the interior wall panels are load-bearing, but there is complete flexibility as to material and configuration for non-structrual partitions, closets, bedrooms, kitchen and service quarters.

2.2 <u>Exterior Panels</u>. The main facade walls are not load bearing and can be designed to any configuration from small window openings to curtain walls. End walls or gable walls are load bearing and are, therefore, limited in the size and number of openings.

The balcony module is bolted and grouted to the exterior concrete walls of the building through threaded insert cast into the side walls, Figure 19.

2.3 <u>Joints</u>. Cast-in-place jointing , is one of the outstanding safety feature of this system. After the

horizontal and vertical elements are positioned and checked for plumb and level, concrete is poured into channels between the components. This creates a continuous, integral structure, without welding.

3. <u>Mechanical System</u>. Mechanical sub-systems such as HVAC and plumbing are completed in the conventional manner, however, required conduits are incorporated in the panels at the plant.

4. <u>Electrical System</u>. Electrical conduits can be incorporated in the panels at the plant, but is completed conventionally on-site.

5. <u>Kitchen and Bathroom</u>. These sub-systems are also done conventionally on-site.

6. <u>Transportation and Erection</u>. The highway transportation was accomplished by using fifth-wheel semi-trailer fitted with a padded steel A-frame which could accommodate two panels (one on each side). This frame extended below the chasis to within 12 inches of the ground, in order to lower the overall height of the loaded panels and avoid the necessity of obtaining a special permit for movement.

Erection was done by cranes with lifting capacity of up to 125 tons.

Fig. 16- A Profile of Camci System
(Ref. 33)
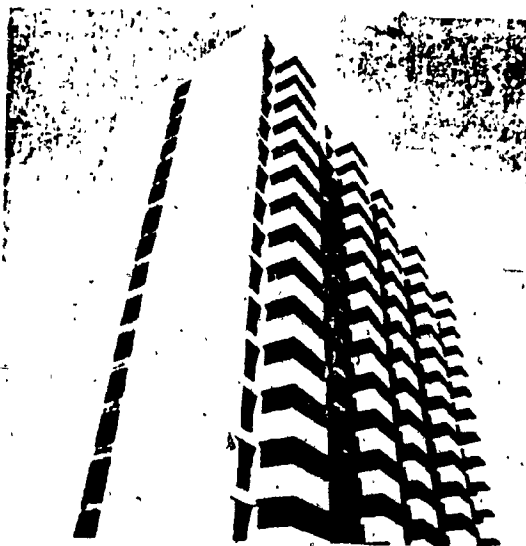
Fig. 17- Camci Balcony
Arrangement
(Ref. 34)
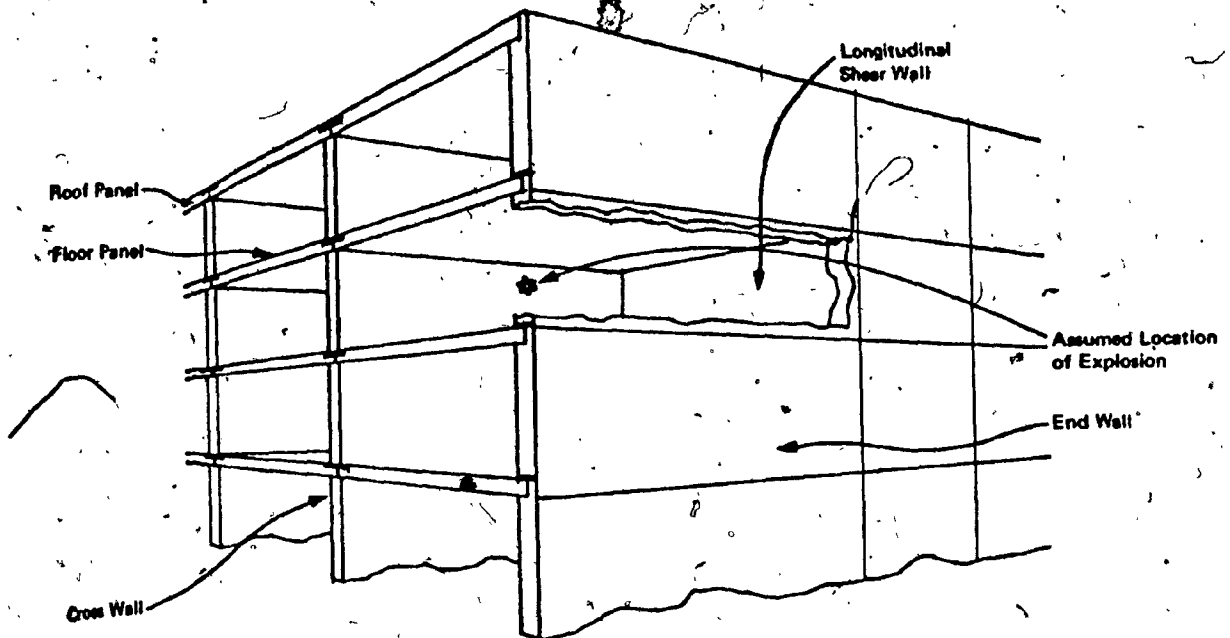
Fig. 18- Camci System; Corner Panel Removed by Abnormal Loading (Ref. 32)
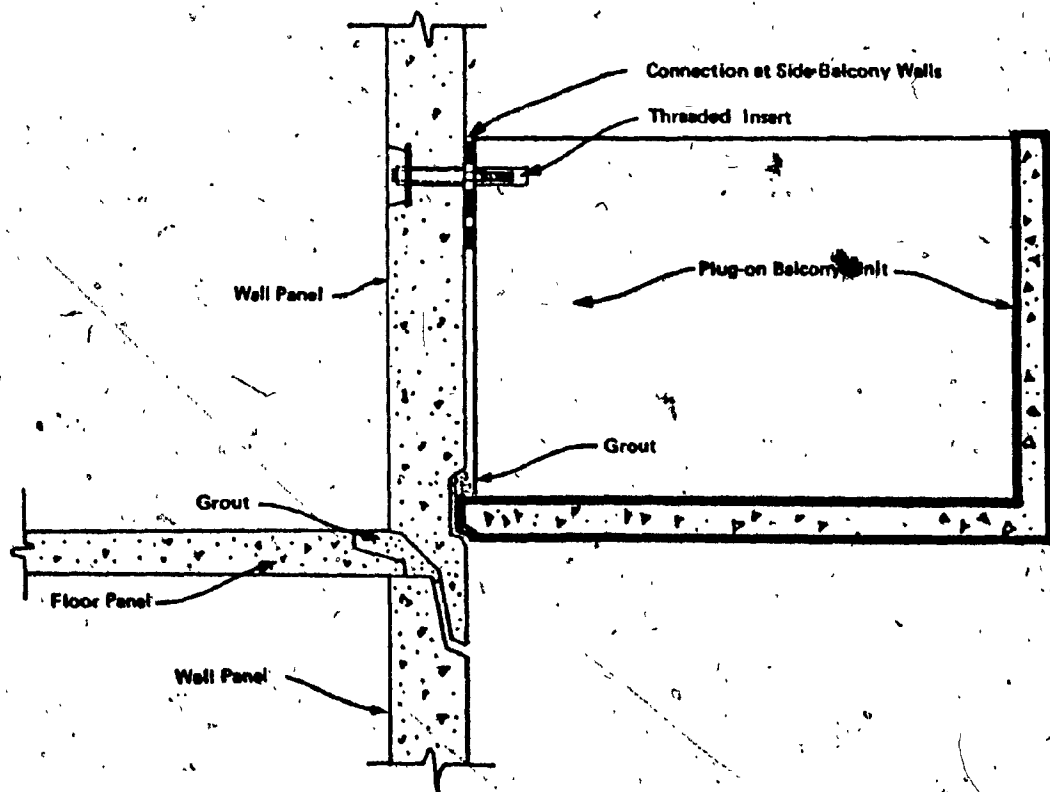
Fig. 19- Section of Plug-On Balcony Unit (Ref. 32)

3.1.3 Componoform System

1. General. Componoform System withdrew from the
Operation BREAKTHROUGH program prior to submission of a
final proposal.(Due to concern over loss of patent rights to U.S.
Gov.). This system was founded in 1965 to develop and
implement building systems that offer both the methedology
and the physical components for the planning, design, and
erection of a large variety of buildings, such as low-cost
housing to luxury hotels, low-rise apartments to high-rise
apartments, office building, shopping centers, schools,
and even complete modular cities.

The system consists essentially of three subsystems:

1. Precast concrete structural framing elements,
   such as beams and columns.

2. Prefabricated modular non-load bearing exterior
   wall and partition components.

3. Integrated modular utilities and mechanical
   services.

These subsystems can be used separately or in
combination.

Mobile plant can be temporarily installed on the
building site and plant fabrication done on location if
conditions permit.

By casting the components in a variety of sizes,
Componoform can put up almost any size building. Bays can
vary between 10 ft and 34 ft, square or rectangular, floor

to floor can be up to 15 ft; 20 stories are the standard limit but the company lists unlimited as special. Figures 21 to 23 show different profiles of this system.

2. <u>Structural</u>. The precast structural system is composed of column, beam, floor slab, stair, elevator shaft, and truss member. Figure 20. Floor slabs, enclosure panels and circulation elements are normally not required for strctural frame stability and may be used at the designer's or architect's discretion. Different size of structural elements can be achieved without altering the basic engineering fundamental to suit individual building requirements. For example, a column may be cast to form one, two, three or four armed column components. Description of structural components are given in the following table.

2.1 <u>Joints</u>. During erection the cross-beam columns are first fastend in place, then tie beams of variable lengths are lowered into position between the arms of the columns and joined to the cross-beam arms. Connections between these members are either bolted or welded, then grouted, Figure 24. Various other precast elements such as stairs, elevator cores, exterior window walls, etc. are then attached to the frame structure. Floor slabs are also grouted at the chamfered long edges.

3. <u>Mechanical System</u>. All mechanical elements such as HVAC, plumbing and elevator are integrated in the system.

Fig. 20- Componoform Structural Component (Ref. 25)

Column
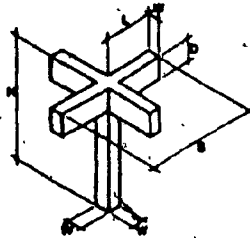
Beam
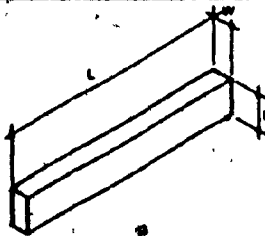
Floor Slab
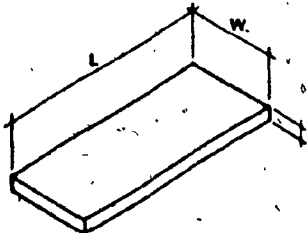
Stair
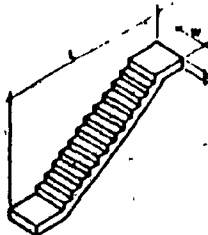
Elevator Shaft
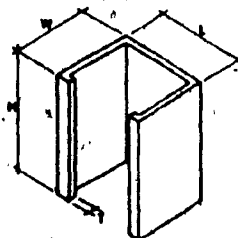
Truss Member
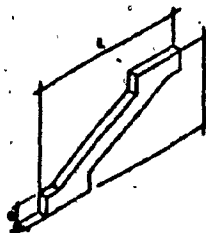
Description of Componoform Structural Components

Dimensions			Weight	Material	Notes
Maximum	Minimum	Optimum (approx.)	Per optimum piece (approx.)		
Column					
H 16' – 0"	–	9' – 0"			Any arm may be
W 32" x 32"	12" x 12"	12" x 12"			blocked off in casting
S 14' – 8"	12"	9' – 0"			
Column Arm			6000 lbs	concrete	
L 6' – 0"	–	4' – 0"			
W 32"	12"	12"			
D 24"	12"	22"			
L 24' – 0"	–	12' – 0"	1600 lbs	concrete	
W 32"	12"	12"			
D 24"	12"	22"			
L 30' – 0"	–	20' – 0"	12,000 lbs	concrete	Cast with hollow cores
W 8' – 0"	–	8' – 0"			to reduce weight
T 12"	8"	10"			
L 32' – 0"	–	20' – 0"	6000 lbs	concrete	
W 8' – 0"	–	3' – 0"			
T 12"	8"	10"			
L – –	–	7' – 0"	9600 lbs	concrete	
W 8' – 0"	–	6' – 0"			
H 9' – 0"	–	9' – 0"			
T 12"	6"	6"			
L 32' – 0"	12' – 0"	24' – 0"	7000 lbs	concrete	
W 32"	12"	12"			
H 9' – 0"	–	8' – 0"			
D 24"	12"	22"			

The mechanical services are located either above or below
the plane of the horizontal structure, so they can cross
from one bay to another. Figure 25.

Plumbing chases run vertically through openings
provided in the structural slabs.

4. Electrical System. Electrical conduits run
horizontally in the grooves between structural floor slab
or in underfloor raceways set into the finished floor.
Figure 26.

5. Kitchen and Bathroom. Kitchen is premanufactured
and then inserted into living unit bay. Figure 27.

Bathroom is also premanufactured and then attached
to mechanical service core. figure 28.

6. Transportation and Erection. All structural
elements such as columns, beams, floor slabs, stairs,
elevator shafts, fascia panels and exterior walls are
transported to the site from the plant on flat-bed trailer.

All the elements are raised into their final
positions by cranes.

ISOMETRIC
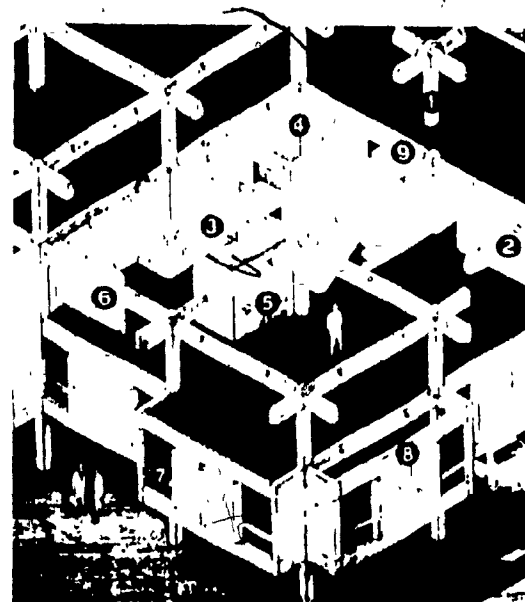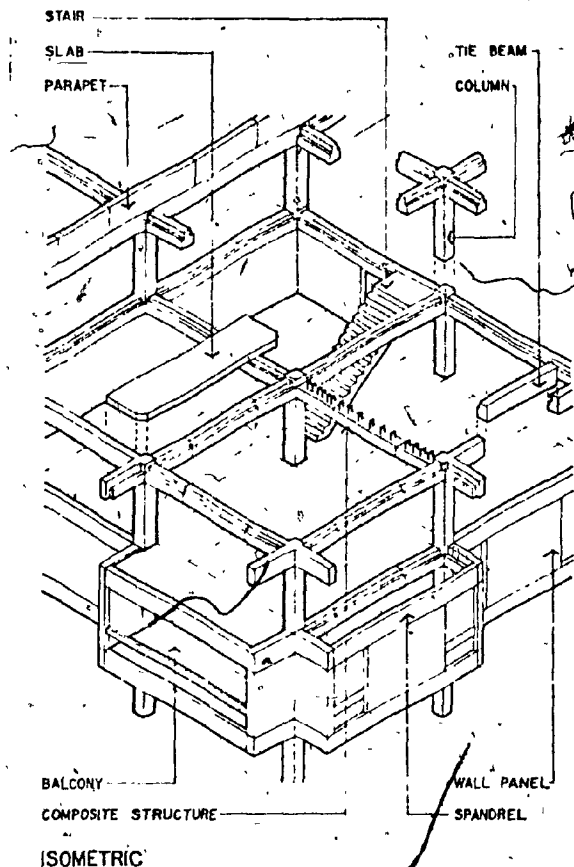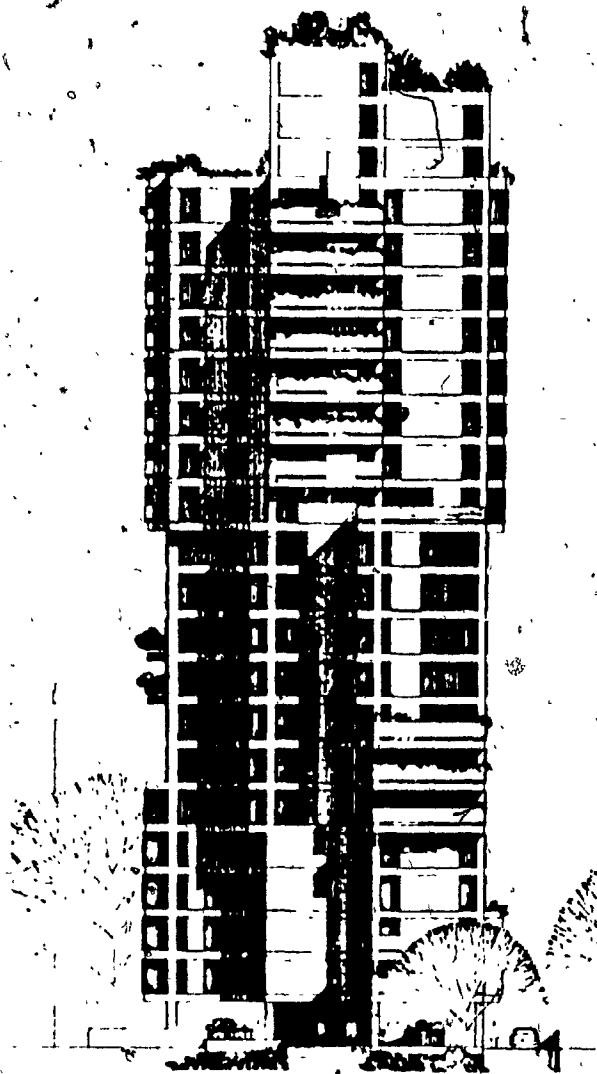
Figures 21, 22, and 23-

Different Profiles
of Componoform
System (Ref. 25)

Artist's drawing shows cutaway of
building section. The primary struc-
tural members of the Componoform
System are: (1) column, (2) tie beam,
and (3) floor slab. Also shown are: (4)
elevator shaft, (5) premanufactured
bathroom unit, (6) exterior wall
panels, (7) window panels, (8) facia
pieces, and (9) precast stair.
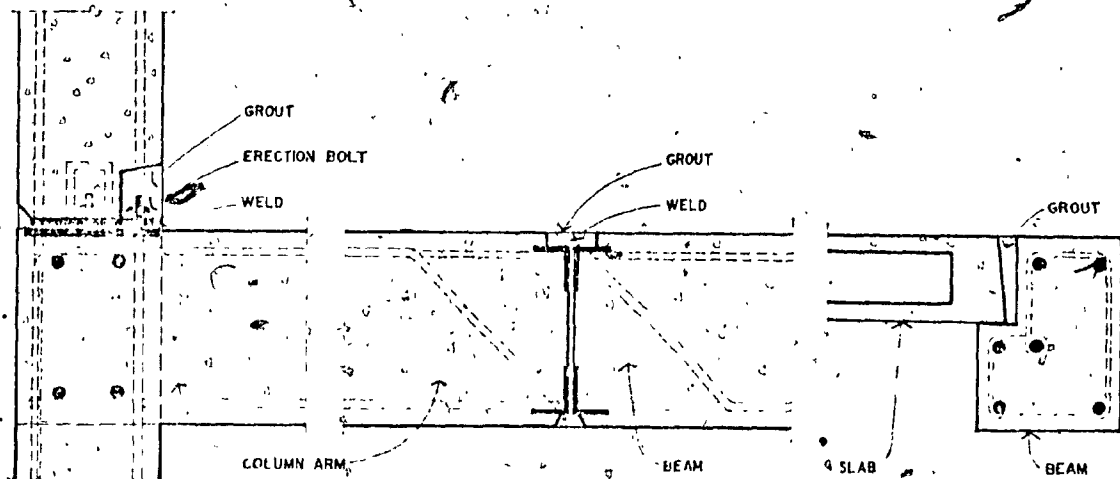
Fig. 24- Componoform Typical Joint Section (Ref. 25)
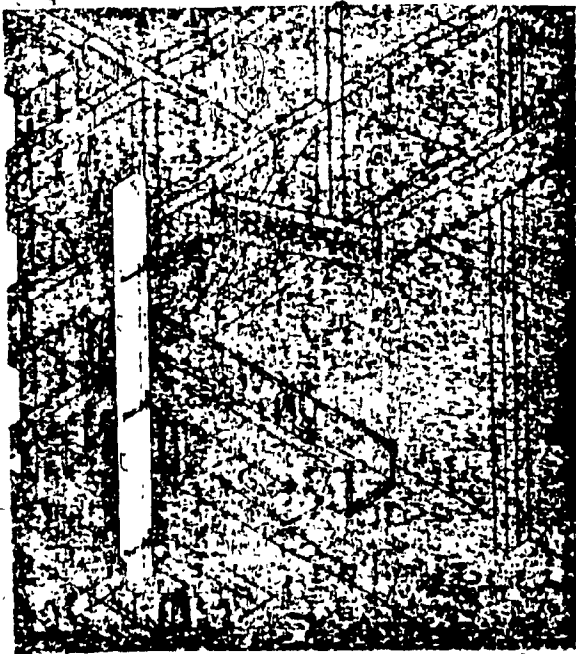
Fig. 25- Main-Truck Mecha-
nical Services
(Ref. 25)
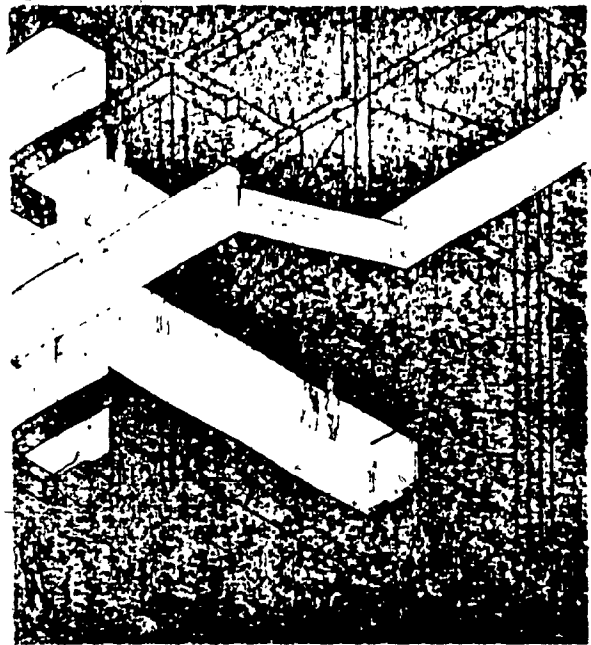
Fig. 26- Long-Span Bridge
Component Carry
Electrical
Services
(Ref. 25)
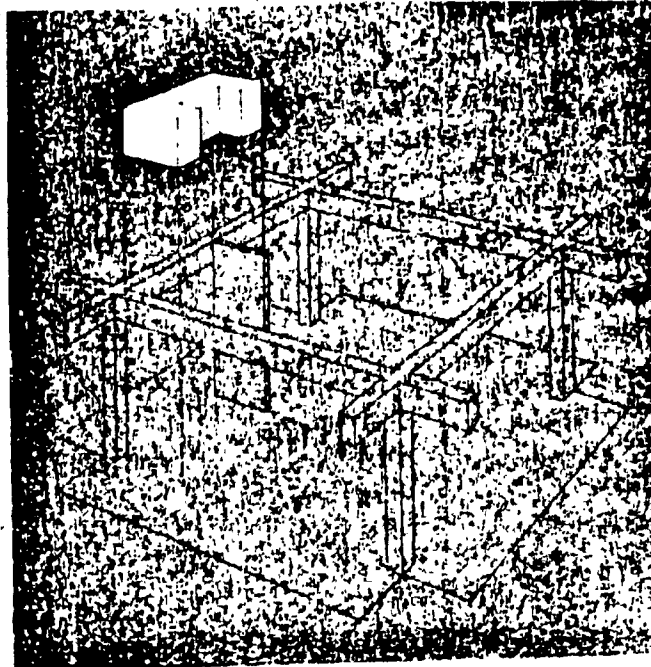
Fig. 27- Pre- manufactured Kitchen Unit
(Ref. 25)
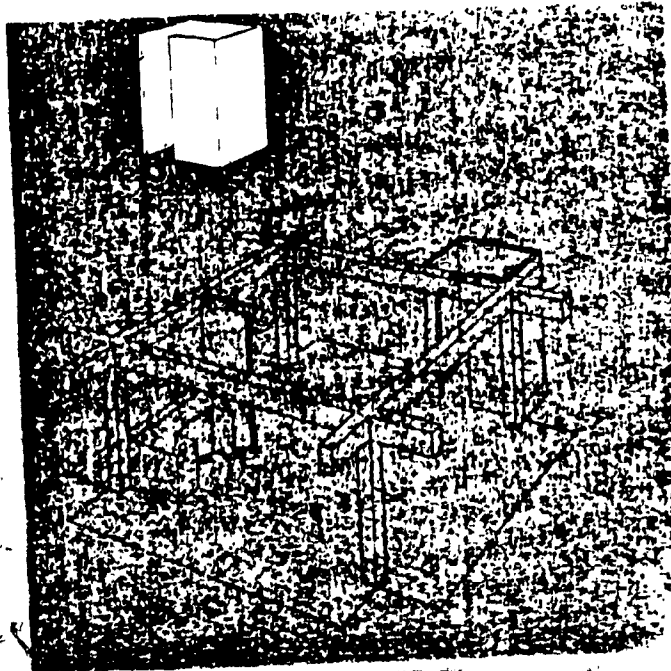
Fig. 28- Pre-manufactured Bathroom Unit
(Ref. 25)

3.1.4 Descon/Concordia System

1. General. Descon/Concordia System was founded in
1969, by a Canadian joint venture of Descon Management
Corporation Ltd. and Concordia Estates Holidays Ltd.
Descon/Concordia System was the only foreign winner in the
Operation BREAKTHROUGH program of the U.S. Department of
Housing and Urban Development.

Descon/Concordia System combines a management system
and a flexibile building system which calls for a rationa-
lized assembly of readily available off-the-shelf components,
or components fabricated through existing processes, and
existing building and manufacturing processes to produce
housing ranging from 2-story town houses to 22-story high
rise structures. It is a system which is not limited to one
source of supply and does not require extensive capital
investment for plant.

The main objective of Descon/Concordia in the
management and building field is to enable construction
industry to meet the challenge of rebuilding the environ-
ment in a manner that responds to human needs.

The Descon Management System has been developed to
plan, control, and monitor all phases from feasibility
studies, design, production of sub-system, through building
erection, to occupancy. Figure 29, shows the basic manage-
ment flow.

The Descon Management Process has been developed
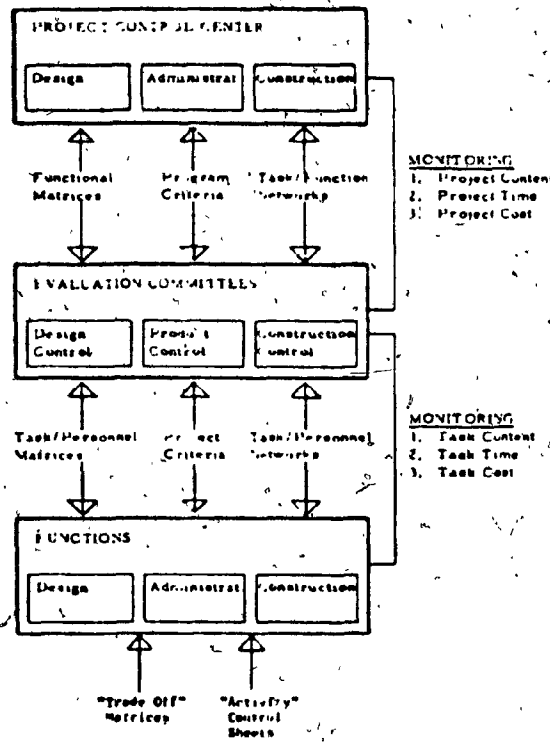
Fig. 29- D/C basic management flow
(Ref. 38)

and proved as an optimum means of planning and controlling project costruction and ensuring consistent quality control.

The Documentation System is a unique system which was developed by Descon Management System specifically for system building. Its features are:

a) All design information can be readily obtained by following the Descon Numbering System which begins at the General Description drawings and proceeds through each sub-assembly down to the shop drawing level of detail.

b) Generic building system details can be adapted to
specific project requirements with little or no
drafting costs, by changing dimension schedules
and specification.

c) All drawing are printed in legal size book-form
which permits easy referance to design details,
both during the design stage and during construc-
tion on the site.

d) Drawings can be transmitted over a telecopier.

Major components of the Descon/Concordia System
include: strcture, plumbing, HVAC, weather-screen, kitchen,
bathroom, storage units, floor and wall panels, partitions,
and door sub-assemblies. Figure 30.

Elevator cores, stairways, and refuse chutes, are
assembled on-site from precast concrete elements, complete
the component mix required in a typical building. Balconies
and sun decks may be employed to add architectural interest
to the building and to accomodate occupants' tastes and
needs. Figure 31, shows different profiles of Descon/Concor-
dia System.

2. <u>Structure</u>. The primary structural components of
D/C system were precast concrete floors, walls and beams.
These panels may be pre-stressed or post-tensioned in
existing precasting plant facilities, or may be cast on
site. Supplementing these panels were non-load bearing
exterior composite panels, complete with interior finish,

window and doors to reduce on-site labor requirements.

A typical wall panels size being 27 ft 4 inches (up to 40 ft) length, 8 ft width and 8 inches thickness; and floor-ceiling panels 21 ft length, 10 ft width and 5 to 6-1/2 inches thickness.

Figure 32 illustrates response to abnormal load. In case of progressive collapse, bearing walls AB and DC will remain in place when subject to 720 psf. This is accomplished by the addition of steel reinforcement to the wall panels and positive mechanical connections between bearing walls and adjacent floor slabs. Floor slabs AD and BC contain strong zones which are additionally reinforced to remain in place at 720 psf loading and provide lateral support for the bearing walls.

2.1 <u>Joints</u>. One of the innovative feature of D/C system is dry mechanical joints. Mechanical connections between elements are by a patented field friction bolting technique. The advantages are almost in the erection cycle:

  a) Bolting does not require skilled labor.

  b) It is not time consuming.

  c) It is a dry process and relatively weather
     independent.

  d) It is easily produced and tested.

Its disadvantages, however, are almost all in manufacturing cycle:

  a) Mechanical joints as a whole require closer

tolerances, or at least uniform tolerances for elements to fit together.

b) Inserts tend to become complicated specialties, and once adopted, the possibility of trading them off or change them becomes difficult.

c) A high degree of preparation and prefinishing is required in the plant in order to optimise erection work.

d) Modular coordination is absolutely essential for sequence of erection, operation, scheduling, and mass production requirements.

Through D/C management tools and technique all the above difficulties would be aleviated, if not entirely eliminated, by virtue of the fact that they occure in the manufacturing process where quality control under plant conditions is not only possible, but easily achievable under present industrial conditions.'

Steel inserts are embedded in the concrete panel and held in place by stud-welded anchor bolts. During erection when two such elements are placed adjacent to each other, a steel make-up piece is friction bolted to take up manufacturing and erection tolerances. Figures 33 and 34.

3. Mechanical and Electrical Systems. The D/C system use a light weight, prefabricated, plumbing, ventilation and electrical service chase placed floor-to-floor adjacent to the bathroom and kitchen modules. Figure 35.

In order to provide the equivalent of a 1 hour fire endurance for the chase, a sprinkler head is added to a cold water line below the floor slab plug which is built into the service chase. The units are linked vertically utilizing speed connectors. Figure 36.

Heating and cooling may be through use of conventional units installed in a closet architecturally combined with the balcony on an exterior wall, and distributed from there by forced air. In some cases, electric base-board heating may be satisfactory.

4. <u>Kitchen Module</u>. D/C kitchen modules contain all appliances, counter tops, cabinets, lighting and plumbing which are associated with any conventionally built kitchen. Modules can be combined to provide a variety of kitchen arrangements from galleys to "L" shaped dining-kitchen types. Figure 37.

The structural system of the module is non-load bearing in service and is designed to resist only forces encountered during transportation. Back and side walls are constructed of wood or metal studs which have an interior finish and exterior finish dependent on finish requirement in the apartment.

5. <u>Bathroom Module</u>. D/C bathroom module are pre-manufactured modular components of three basic units, i.e., bath/shower, sink/water closet, and filler units.

All are designed for speedy field connection to the mech-
anical/plumbing module. Standard parts can be assembled to
form simple powder rooms or large multi-use bathroom.
Storage and other accesories are available for all bathroom
assemblies. Many safety features have been incorporated.
Figure 38.

6. <u>Transportation and Erection</u>. The highway trans-
portation was accomplished by using fifth-wheel semi-trailer
fitted with a padded steel A-frame which could accomodate
two panels (one on each side). This frame extended the
chassis to within 12 inches of the ground, in order to lower
the overall height of the loaded panels and avoid the
necessity of obtaining a special permit for movement.

Erection was done by crane with lifting capacity up
to 125 tons.
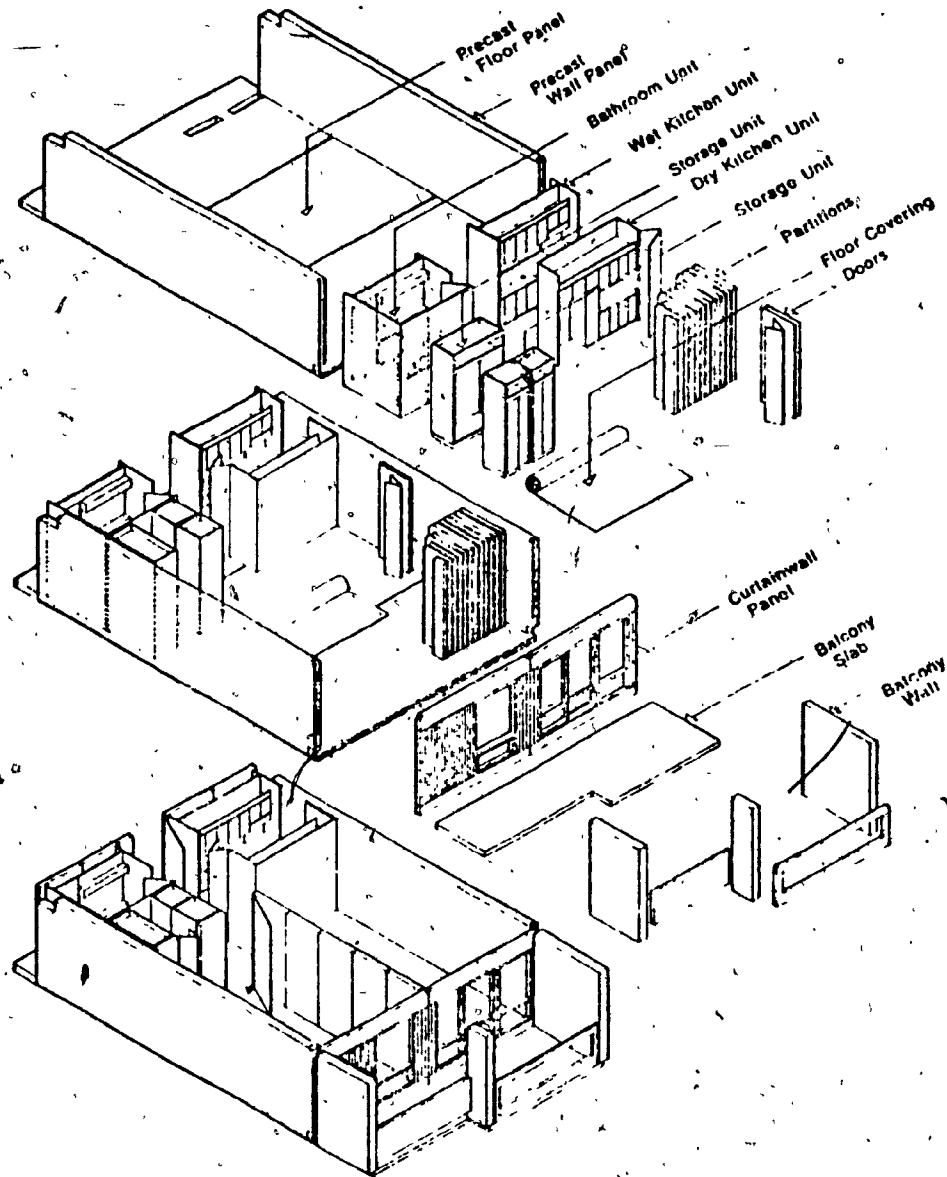
Fig. 30- Descon's Building Components
(Ref. 38)
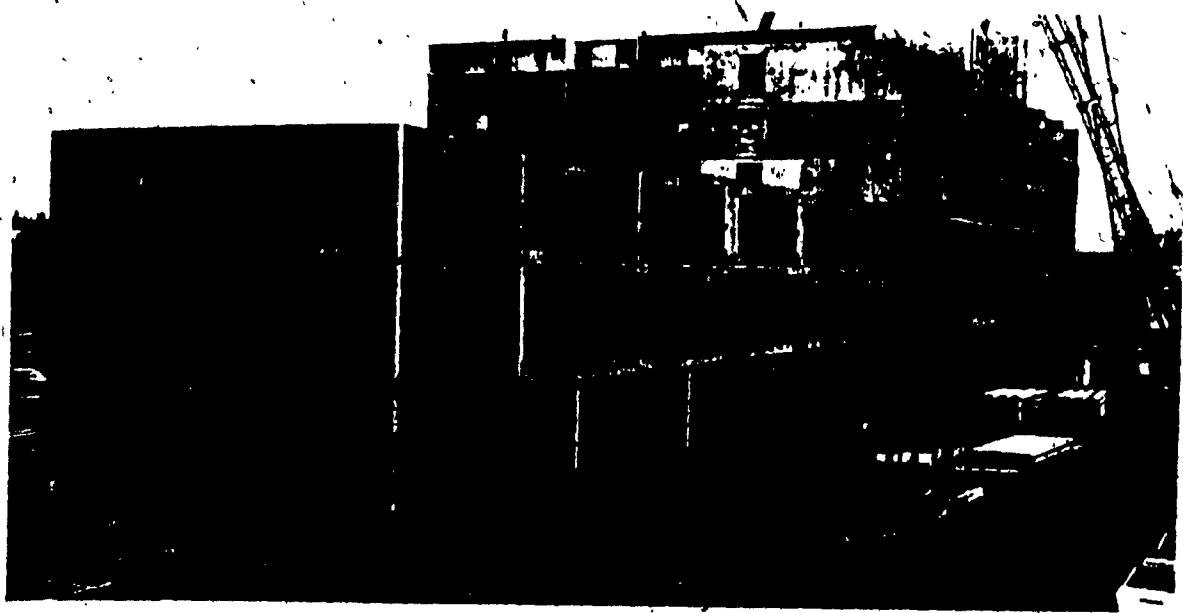
Fig. 31- Decson's Residential Apartment Building
75% Completed (Ref. 33)
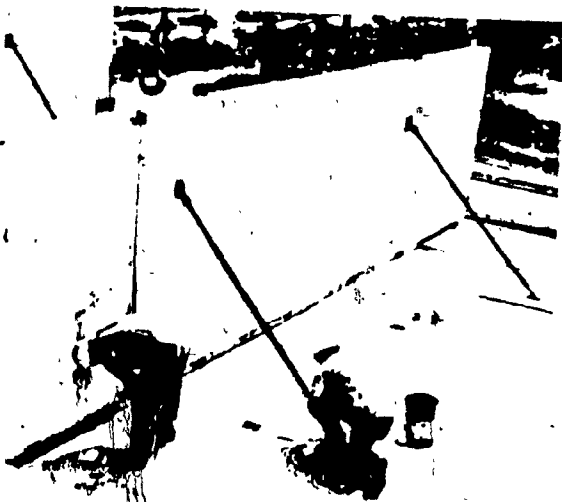
Fig. 31- Wall-Bracing Used
During Assembly of
Descon's units
(Ref. 33)

Fig. 31- Completed Descon High-Rise
(Ref. 34)
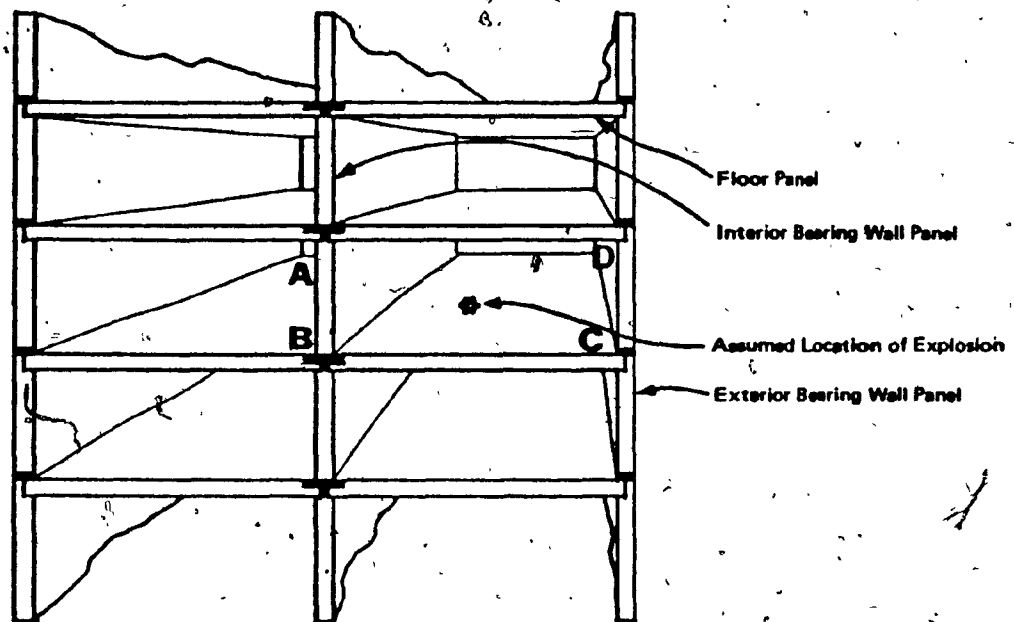
Fig. 32- D/C, Response to Abnormal Load
(Ref. 32)
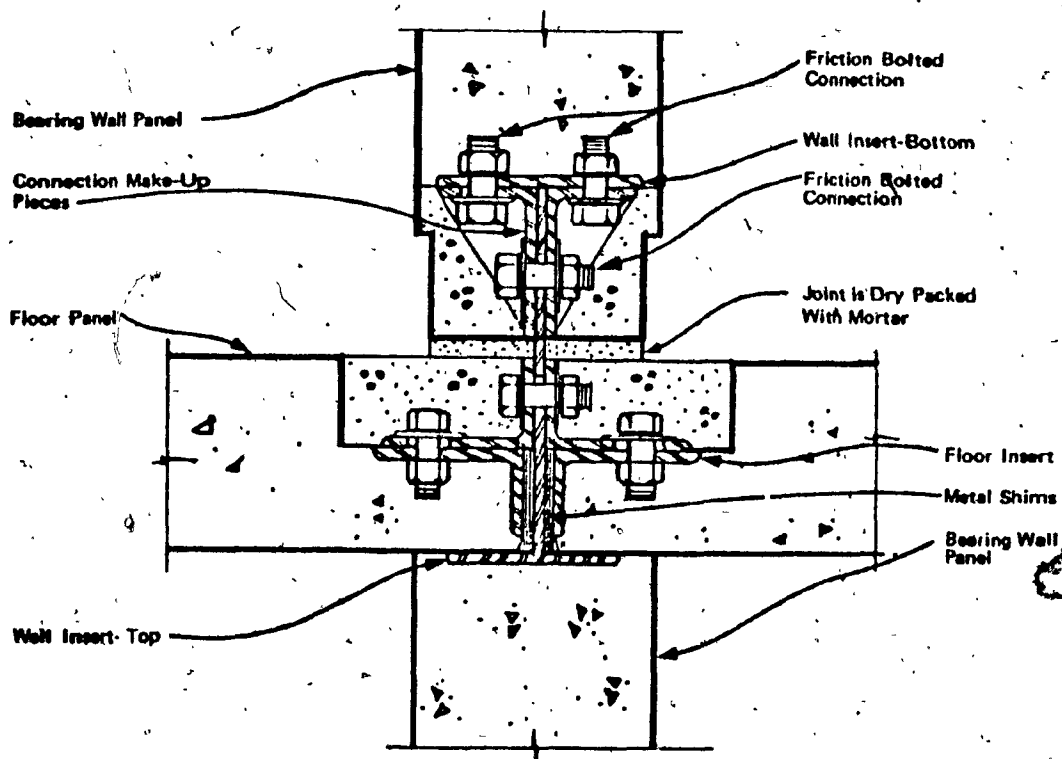
Fig. 33- D/C, Internal Wall to Floor Connection
(Ref. 32)

Cladding
Wall Bottom Insert
Dry Packed
With Mortar
Floor Insert
Wall Top Insert

Exterior Bearing
Wall Panel
Friction Bolted
Connections
Connection Make-
Up Pieces
Floor Panel
Exterior Bearing
Wall Panel
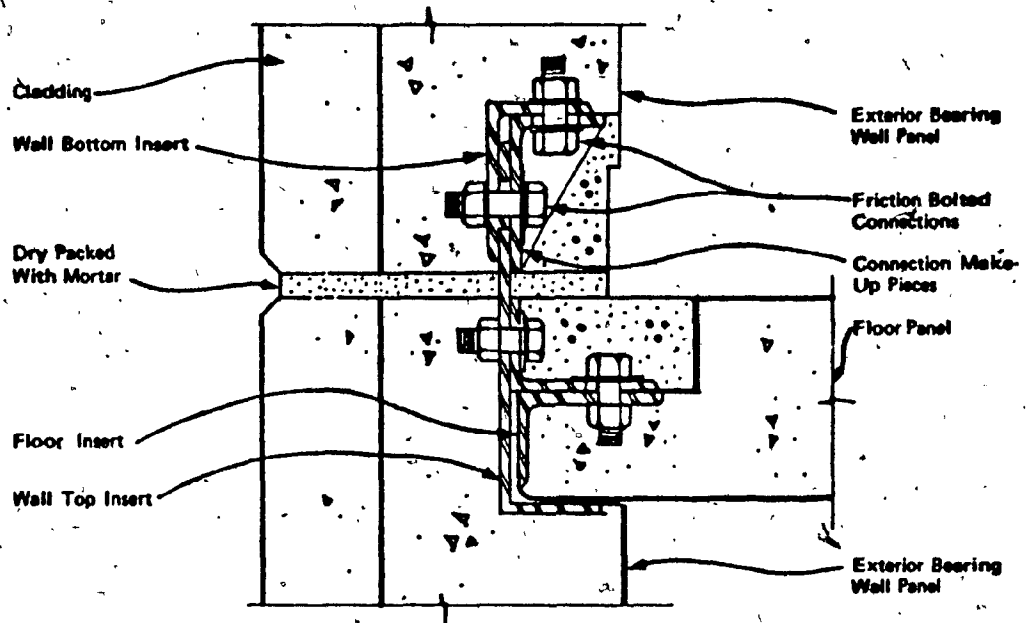
Fig. 34- D/C, Exterior Wall to Floor Connection
(Ref. 32)

Kitchen Modules

Floor to Floor
Service Chase
Concrete Floor Slab Plug
at Bottom of Each Chase Section
Sprinkler Head Located on
Cold Water Supply Below
Floor Slab Plug
Bathroom Modules
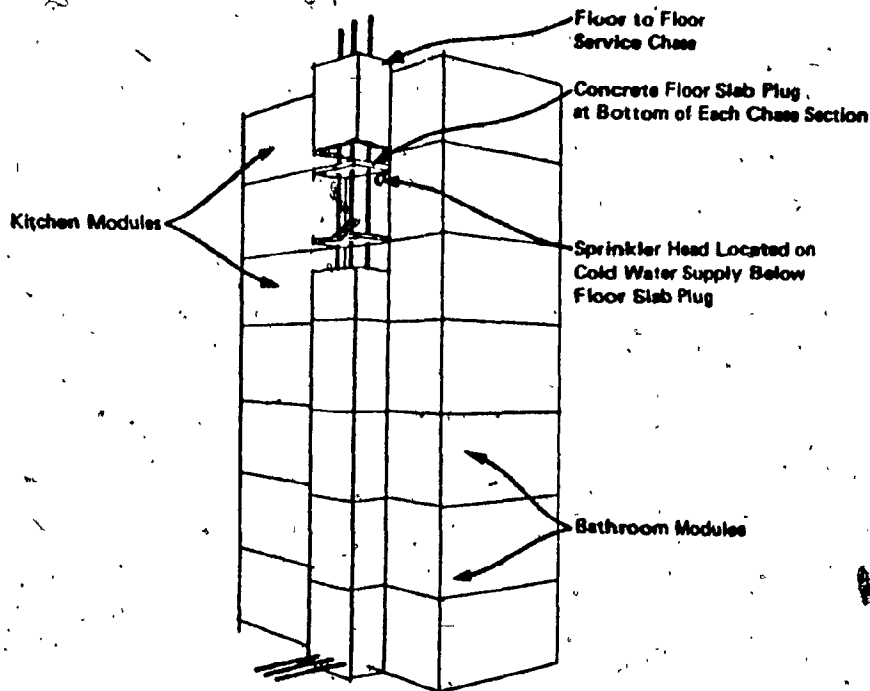
Fig. 36- Service Chase Adjacent to
Bathroom and Kitchen Modules
(Ref. 32)
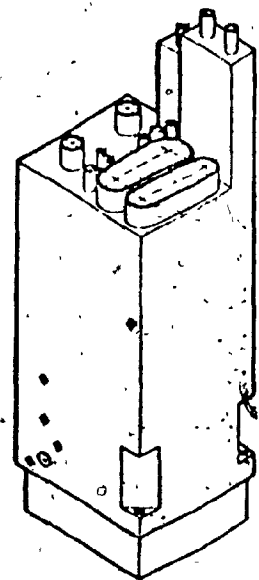
Fig. 35- Service
Module
(Ref. 26)
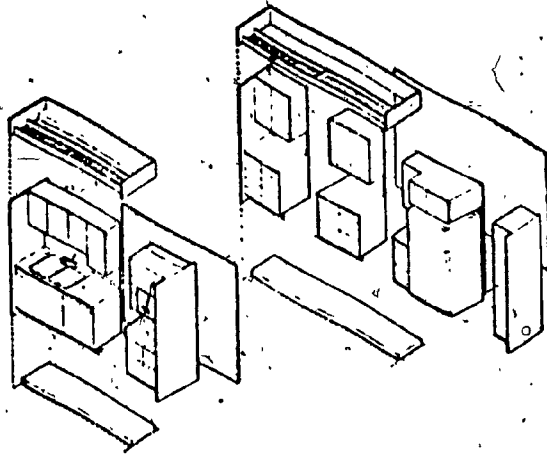
Fig. 37- D/C, Kitchen Module
(Ref. 26)
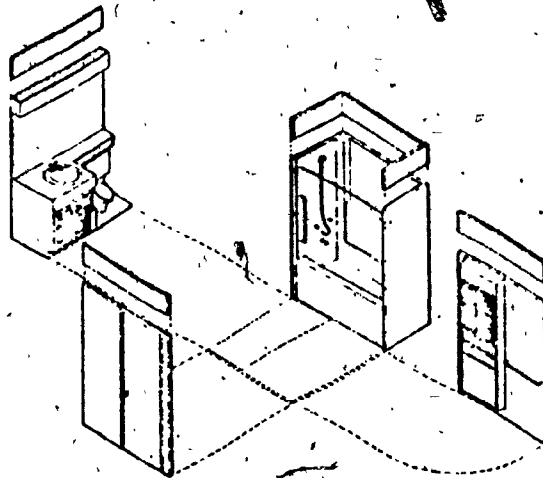
Fig. 38- D/C, Bathroom Module
(Ref. 26)

3.1.5. FCE-Dillon System

1. <u>General</u>. FCE-Dillon System uses a combination of pre-cast components and pour-in-place concrete to form a monolithic structure. The system is flexible through various configurations of the basic components, building of various shape and sizes. The same basic system can be used for high rise structures, multi-family low-rise apartments, single family attached dwellings, hotels, dormitories, hospitals, and certain non-shelter structures. Figures 39 and 40 show different profiles of this system.

This system is applicable to urban, suburban and urban renewal projects. Also it is adaptable to all national climates, and to all normal soils with slopes upto 12 degrees.

The especial feature of FCE/Dillon System is its three major patented subsytems; the Heart Module, the Elevator Module, and the Mechanical Penthouse. Each of them will be explained later on.

2. <u>Structure</u>. The precast concrete component is the basic structural nucleus of the system. This consists of principally of walls and floors which are partially precast under controlled factory conditions.

The precast concrete bearing walls are steel reinforced and cast to a normal thickness of 8 inches and a maximum length of 30 ft. They have hollow core openings

that run vertically the entire height of the wall and accomplished two objectives:

    1) They reduce the weight of the walls, facilitating transportation and handling.

    2) They play an important part in the structural integrity of the system.

Figure 41. The floors or deck slabs are precast, prestressed concrete member. These slabs are cast either 4 inches or 6 inches thick and 6 ft or 8 ft wide and are available in length of upto 32 ft.

The balcony is precast, prestressed concrete slabs with sleeves cast into them to accept a railing.

In response to an abnormal load in case of progressive collapse, as shown in Figure 42, partition EF will fail laterally. Wall DK will remain in place since it is designed to resist 720 psf by the addition of steel reinforcement. Floor slab GH will also remain intact because of additional reinforcement and vertical support provided by partition IJ. Similarly, floor slab CD remain after application of upward 720 psf force because of resistance of partition AB.

2.1 Joints. The typical interior bearing wall joint is made with a combination of cast-in-place concrete and steel reinforcement. Figure 43. The 4 inches thick floor slabs are placed on the lower hollow core wall, the steel reinforcement is placed and concrete is poured

into the wall cores and onto the slab to provide a total floor thickness of 8 inches.

The typical exterior wall joint is made with a combination of cast-in-place concrete, steel reinforcement. A threaded rod is screwed into an insert cast into the lower wall and then bolted to an angle embedded in the upper wall with stud welded anchor bolts. The floor slab is placed, steel bars are looped around the rod, the concrete topping is poured, and the access pocket is drybacked with concrete to complete the joint. Figure 44.

3. The Heart Module System. It consists of kitchen and bathroom, completely constructed in the factory on 8 inches thick pre-stressed concrete slab, and this module is erected as part of the structure. The Heart Module incorporates plumbing, electrical, ventilating, heating, and air conditioning equipment, plus kitchen cabinets and appliances. Floors, walls and ceilings are completely finished and ready for occupancy. Figure 45.

4. The Elevator Module System. It consists of three major elements:

1) The Elevator Module, is a one-story precast structure completely equipped before installation with rails, doors, and hardware, ready to receive the elevator car

2) The Elevator Car, is pre-assembled either in the

manufacturer's facility or on the job site before installing in the elevator module.

3) The Elevator Penthouse, is a light steel structure equipped perior to erection with all the elevator electrical motors, wiring, and mechanical parts.

The elevator is completely operational a few days after the structural phase of the building is completed. Both a single or double shaft system can be used. Figure 46, shows a typical precast double elevator section.

5. The Mechanical Penthouse System. It is a light structure containing the heating boilers, domestic hot water heaters, make-up air units and central air-conditioning equipment for the building. These units are installed in the penthouse and connected, piped and completely wired prior to its erection. This unit also contains all of the controls for the electrical and mechanical systems.

6. Heating, Ventilating and Air-Conditioning. There are two types of HVAC methods in the FCE-Dillon System.

The first type is a two-pipe, control hot and cold water system. The subsystem consists of fan coil units which are installed in the ceiling of each mechanical penthouse module in the factory. The fan coil unit discharge high velocity air through slot diffuser registers in the module which are flush with the ceiling. The high velocity conditioned air is carried to the outside wall through a

process called the "Coanda Effect". The rapid movement of air from the outside creates a negative pressure by entrapping the air in the space between the air stream and the ceiling. The resulting pressure differential causes the stream to follow the ceiling until velocity slows near the oppositewall. Gradually, induced room air mixes with the stream, tempering the air supply before it reaches the occupied space. Figure 47.

The second type HVAC is an electric incremental unit installed in the exterior wall of each living unit. Individual apartment controls are provided which allow the choice of heating or cooling at any time during the year.

7. <u>Transportation and Erection</u>. This system used a special purpose 15-tons capacity fork-lift truck to handle the factory-completed mechanical core units, called "Piggyback", from the production line to storage, or directly to a flat-bed trailer for movement to the job site. Within the factory itself, a 25-tons conventional bridge crane was used to remove the mechanical core units. The mechanical core units have transported by rail-road over 2,200 miles during the Operation BREAKTHROUGH program. Highway trasportation was used only to move the modules to and from the rail head for piggyback rail shipment. Floor slabs were transported on the flat bedded-trailer and were supported by wooden blocking.

Erection was done by crane with lifting capacity of upto 125 tons.

Fig. 39- FCE-Dillon High-Rise (Ref. 34)

2. Mechanical Core Module

10. Steel Frame Partition

7. Wire Mesh and Steel Bars Added; Concrete Topping Placed on Floor Slabs and in Hollow Core Walls

3. Floor Slabs

6. Exterior Wall

1. Cast-in-Place Wall and Foundation

8. Stairwell Floor Panel

5. Interior Hollow Core Wall

6. Corridor Slabs

8. Stairwell Wall

9. Exterior Curtain Wall

4. Balcony Slab
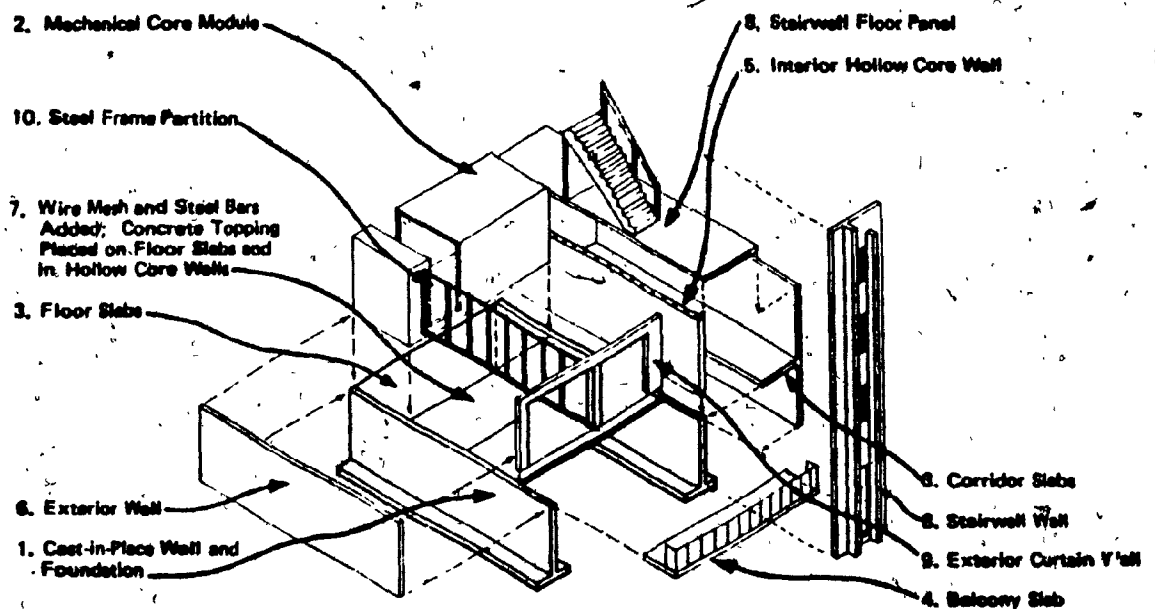
Fig. 40- Construction Components and Schematic of Erection Procedure (Ref.32)
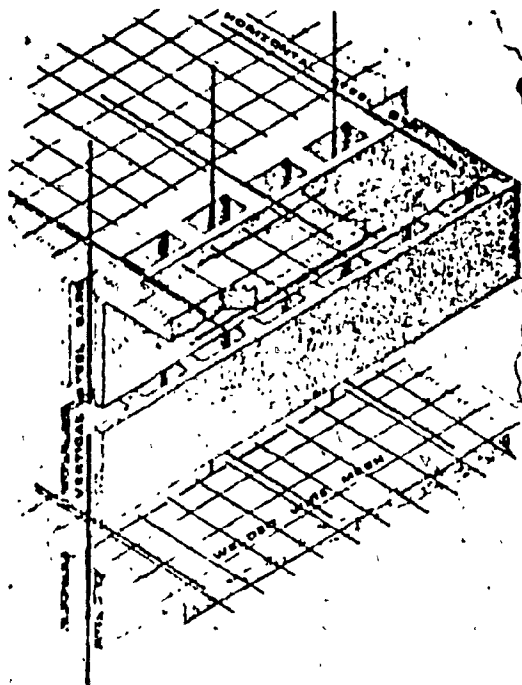
Fig. 41- Reinforcing Steel and Precast Concrete
(Ref. 31)
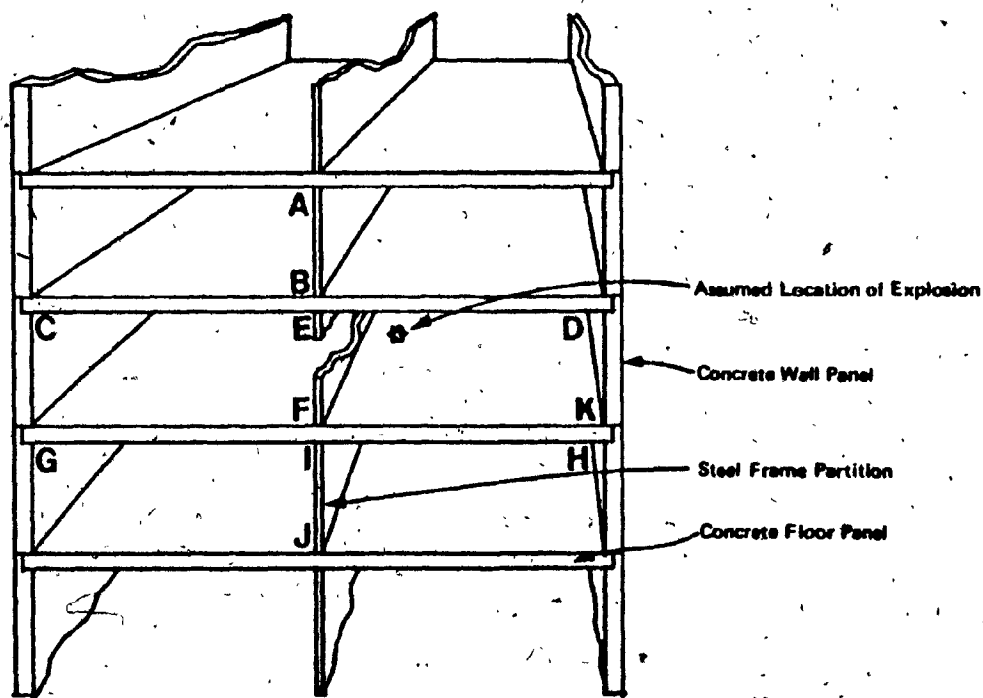
Fig. 42- FCE-Dillon; Response to Abnormal Load
(Ref. 32)

- 62 -
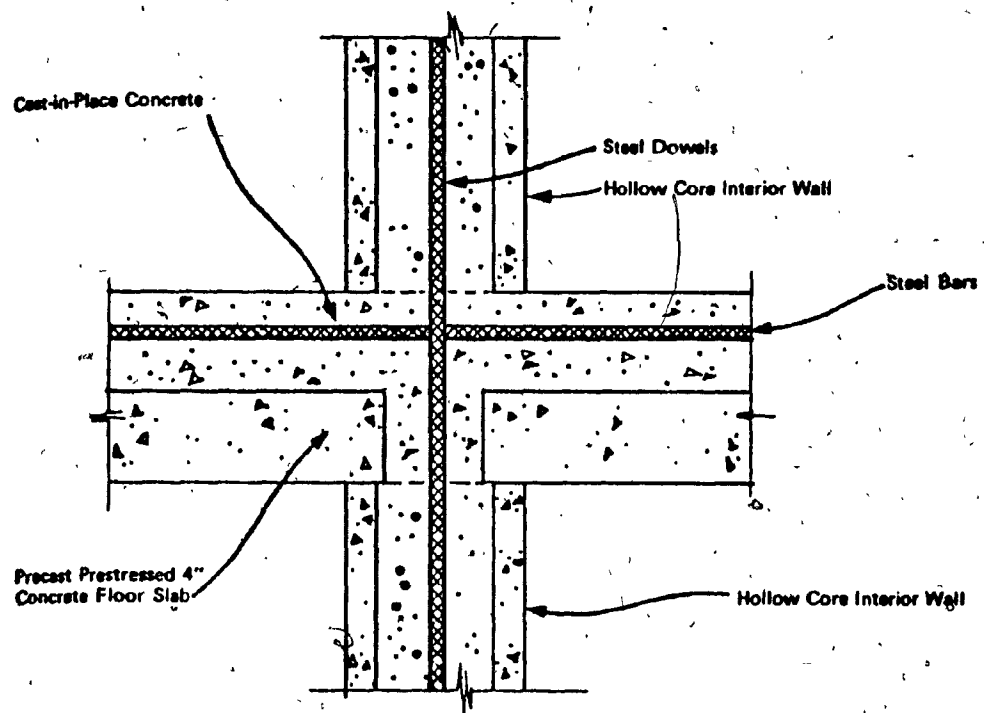
Fig. 43- FCE-Dillon; Detail of Interior Bearing Wall Joint
(Ref. 32)
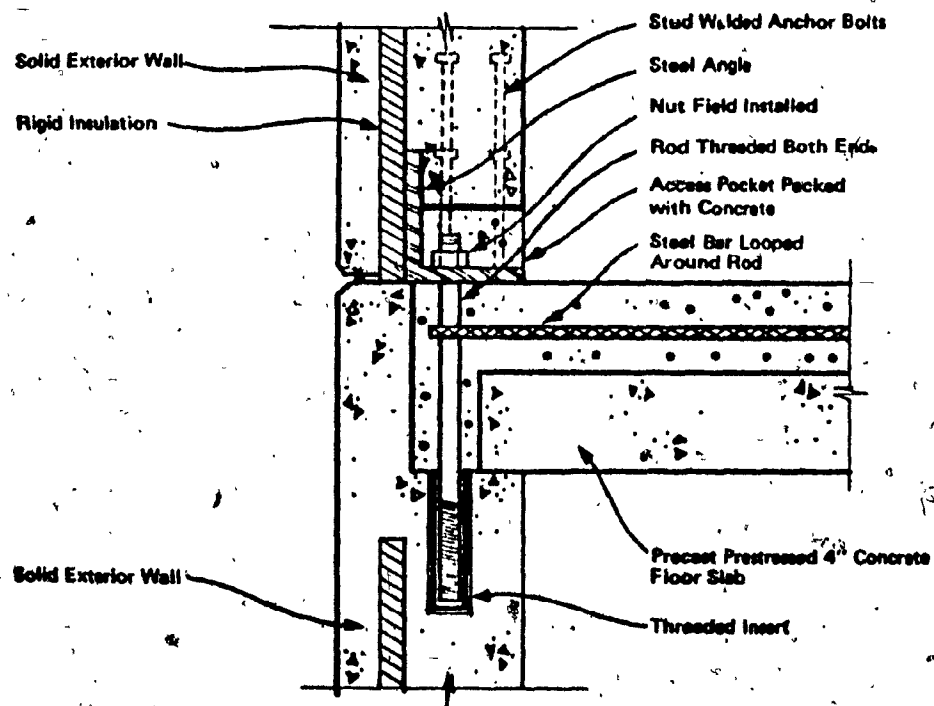
Fig. 44- FCE-Dillon; Detail of Exterior Bearing Wall Joint
(Ref. 32)
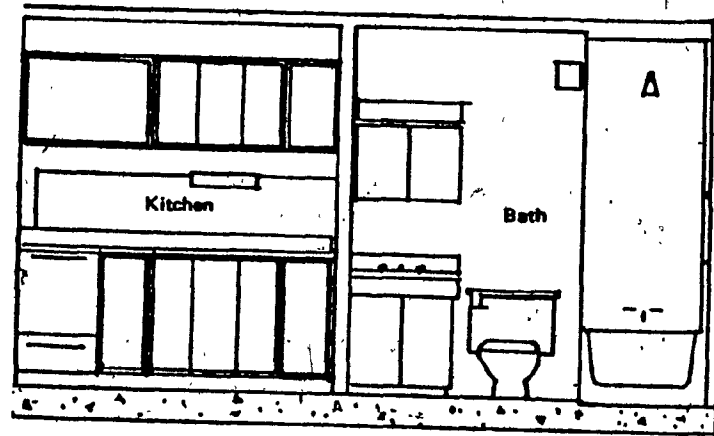
ELEVATION
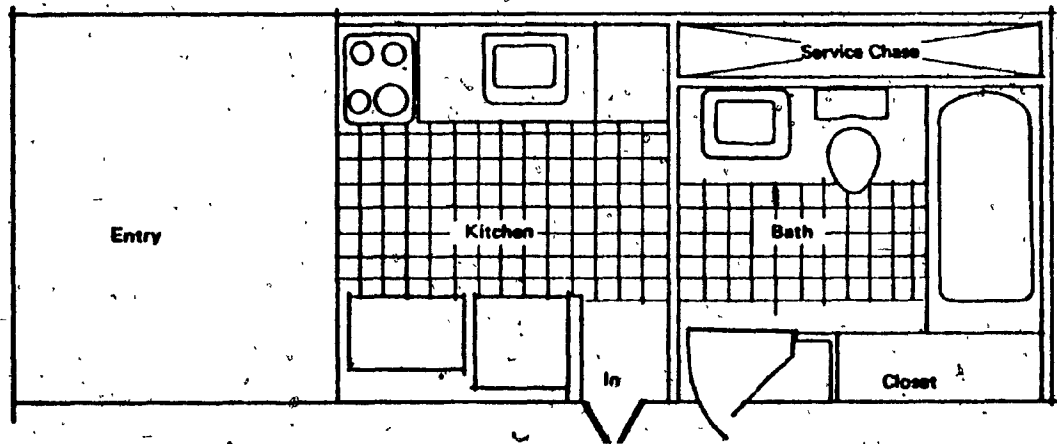
PLAN

Fig. 45- FCE-Dillon; The Heart Module
(Ref. 32)
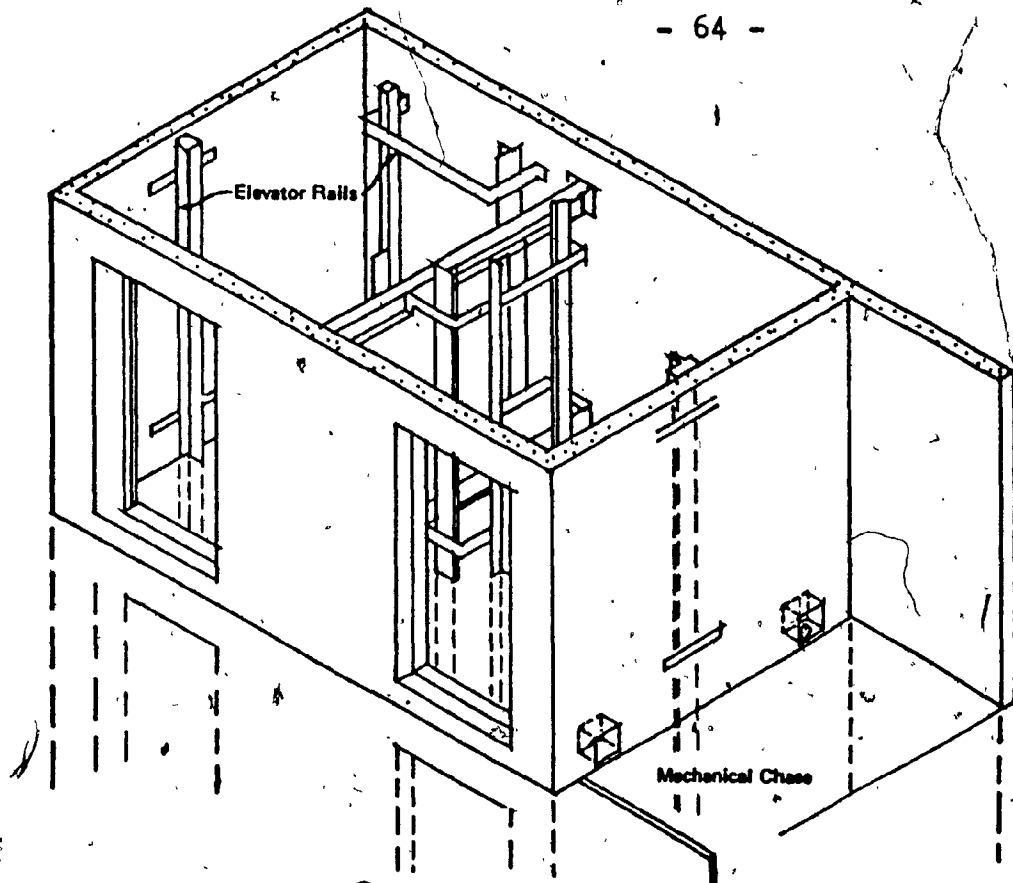
Fig. 46- FCE-Dillon; The Elevator Module,Typical Precast
Double Elevator Section
(Ref. 32)
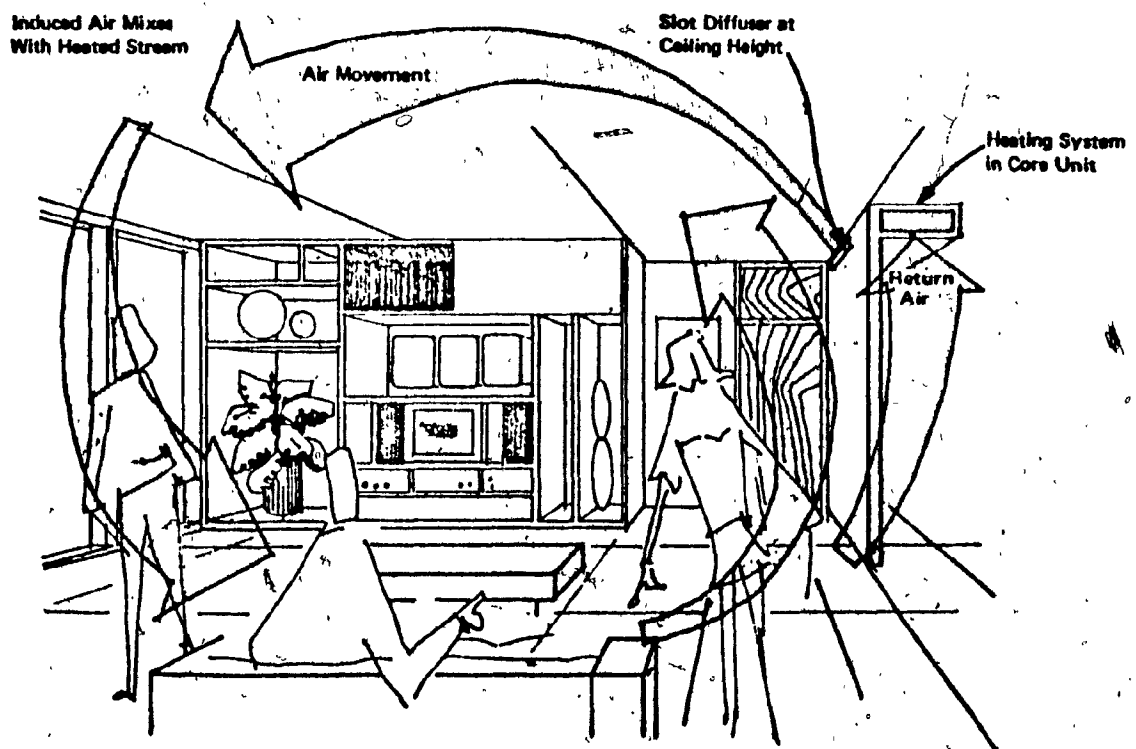
Fig. 47- Air Movement Due To "COANDA EFFECT"
(Ref. 32)

3.1.6. Rouse-Wates System

1. General. The Rouse-Wates System is modified from the parent system developed in England. This system is intended primary for multi-family high, meduim, and low rise structures. It could be adapted to commercial and institutional projects. The R-W system is opplicable to a variety of urban, suburban or urban renewal projects and is adaptable to all normal topography, soil and climatic conditions.

The Rouse-Wates System offers design flexibility. Dimensionally, the precast elements are based upon a one foot grid for building up to 26 stories.

Acoustical privacy is assured due to sound transmission loss of the heavy concrete floors and structured walls, rated at 51 decibels. Other dividing partitions if not concrete, usually gypsum board, are rated to 47 decibels which is superior to sound transmission losses normally found in apartments. Figure 48, shows different profiles of this system.

2. Structure. The Rouse-Wates System is based upon the gravity structure principle and utilized story-high precast concrete walls along with floor and roof panels.

Floor slabs are of solid normal density, reinforced concrete are designed as simple supported single span members. Normally, slabs are 6-1/2 inches thick for spans upto 16 ft, 8 inches thick for spans 17 to 20 ft, and 9

inches thick for spans 21 to 22 ft.

Wall panels are 7 inches thick, solid, normal density concrete. Load-bearing walls are reinforced to resist forces due to lateral and eccentric loads.

In response to an abnormal load in case of progressive collapse, as shown in Figure 49, wall FH is designed to remain in place by the use of special panel and joint reinforcement. Interior wall EG will fail. Elements above will not fail since wall AC is designed to cantilever from the corridor. Some of the floor panels GH are designed as strong panels to resist 720 psf and remain in place to provide lateral support to walls FH, LK and IJ.

Although this system is designed to prevent progressive collapse, the height of building is limited by code to 160 ft. in seismic zones 2 and 3.

2.1 <u>Joints</u>. Joint design achieve complete continuity between panels to allow the structure to act as a series of monolithic story height rigid tables bedded one upon the other. Internal crosswall-to-floor joints features steel loops and interlocking crossbars. Joints are filled with cost-in-place concrete to provide complete rigidity. Figure 50.

The joining between pre-cast concrete cladding panels are based on the "open drain" principle. The vertical joint uses a loose neoprene baffle, the horizontal a shiplap principle. Figure 51.

3. Mechanical System. Mechanical system such as HVAC and elevator are conventional, however, a packaged HVAC unit was developed with Westinghouse Corporation which affords individual tenant control. The unit consists of a prewired and prepiped condenser/evaporator/furnace that is located inside the apartment. A through-the-wall grill is integrated with the exterior concrete cladding. Electric or gas (with power vented flue) may be used. The complete package is lifted into place during erection.

For plumbing, P.V.C. plastic soilwater and rainwater pipe and C.P.V.C. plastic hot and cold water supply are used in this system. Advantages include less expensive material, lighter material and simplified joining techniques. Fire requirements are met by careful detailing of penetration of the building system.

4. Electrical System. Power, T.V. and telephone are distributed to apartment load centers in chases or false ceilings. Within dwelling these services run with a P.V.C. baseboard raceway. The raceway which is shipped in precut lengths for each dwelling, consists of backplate and pre-finished snap-on cover. Figure 52.

5. Kitchen and Bathroom. The kitchen consists of completely furnished interiors whichare manufactured by Westinghouse Corporation. The module contains the electrical distribution center which is prewired for site connec-

tion. The unit with the appliance walls are pushed together
to form a protected box for transportation and erection.
Figure 53.

Bathroom consists of a completely finished box
which is manufactured by American Standard. The tub, floor
and surrounding walls to wainscot height are of molded
fiberglass with a "gel coat" finish. Ceiling is of pre-
finishes aluminum-faced plywood. The limited area of fiber-
glass was to overcome fire requirements.

6. <u>Transportation and Erection</u>. The highway trans-
portation of this system elements were accomplished on flat-
bed trailers.

On the site, these concrete panels and slabs were
raised into their final position by crane with lifting
capacities of up to 125 tons.
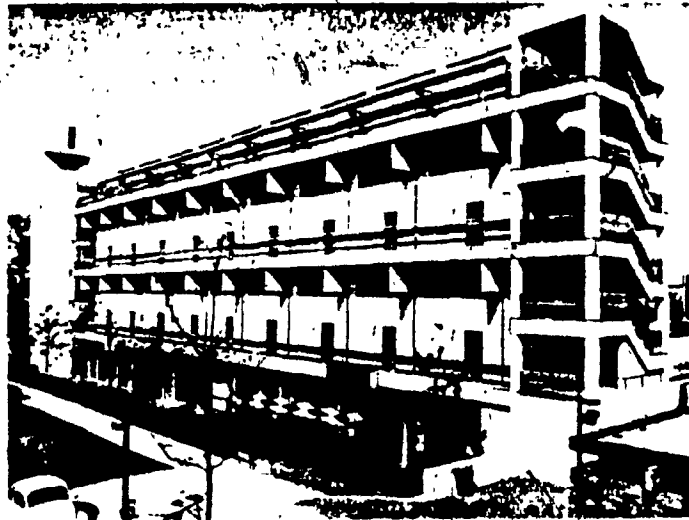
Rouse-Wates Low-Rise

Exterior facade panel, with
window frame and HVAC grill
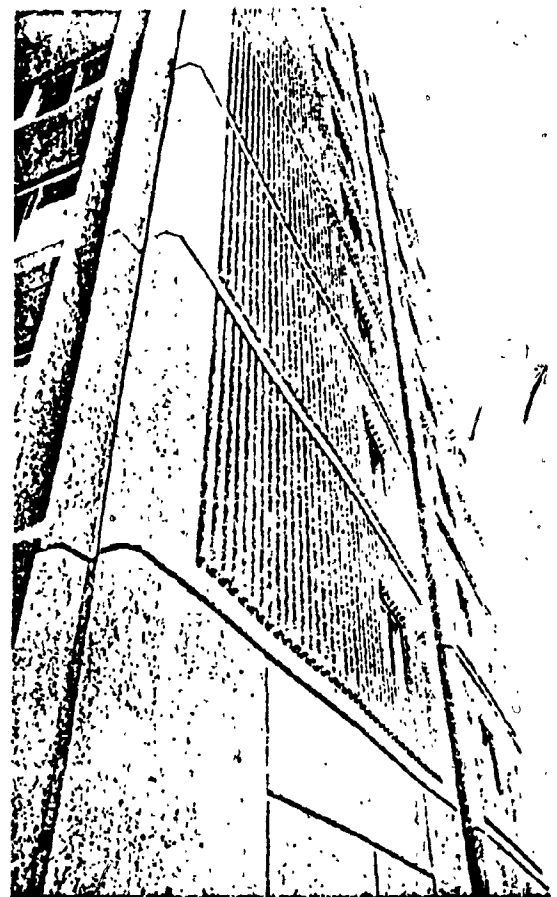
Ribbed exposed aggregate

Fig. 48- Different Profiles of Rouse-Wates System
(Ref. 31)
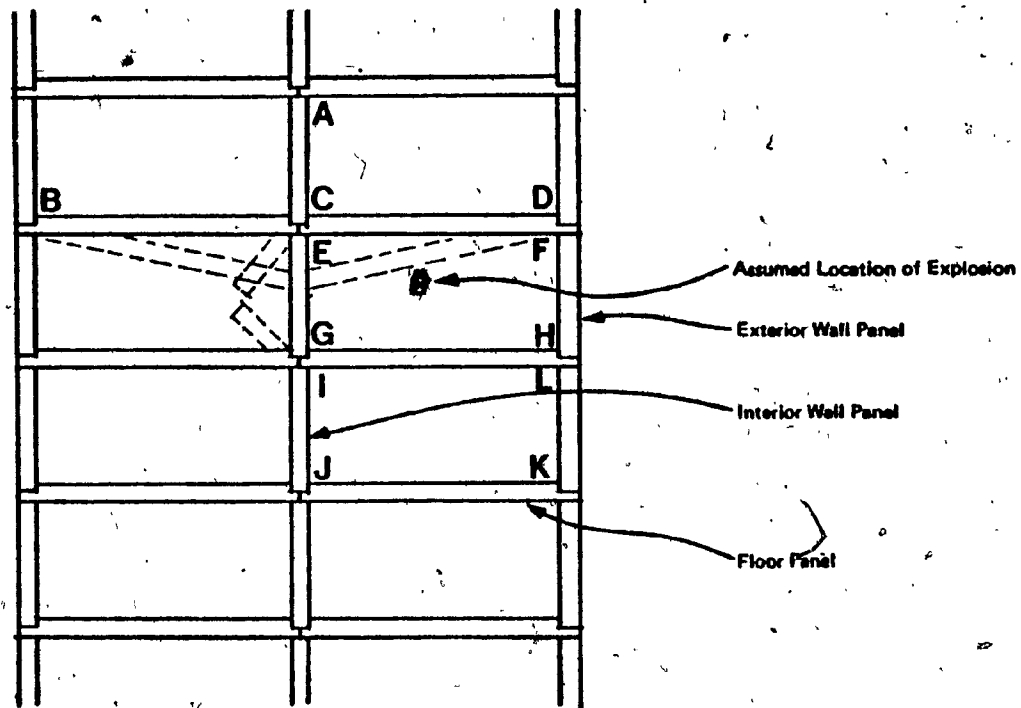
Fig. 49- Rouse-Wates; Response to Abnormal Load
(Ref. 32)
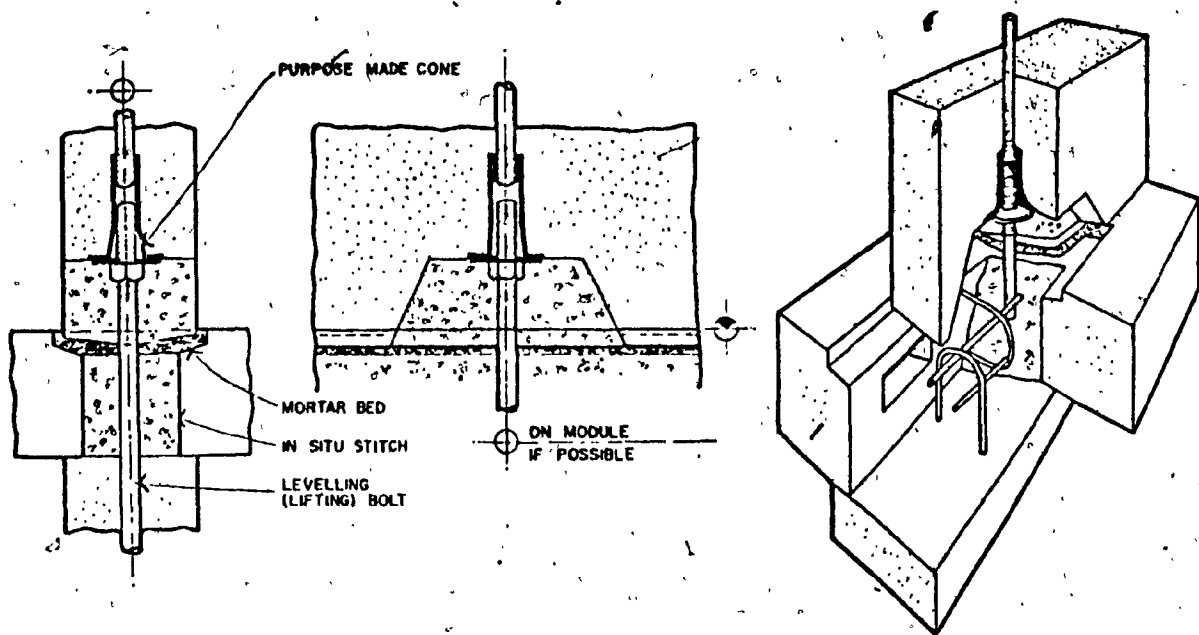
Fig. 50- R-W Typical Internal Crosswall-To-Floor Joint
(Ref. 31)
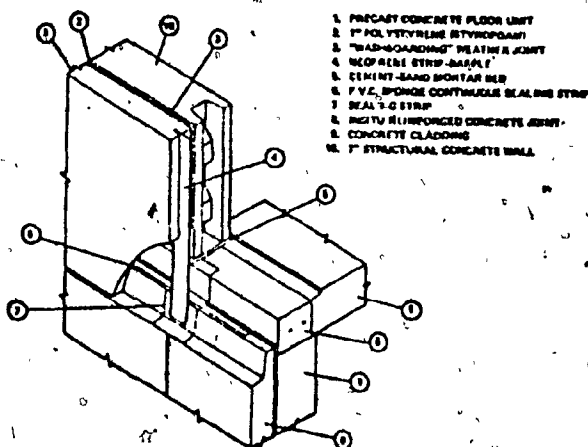
Fig. 51- Precast Concrete
Weathering Joint
(Ref. 31)
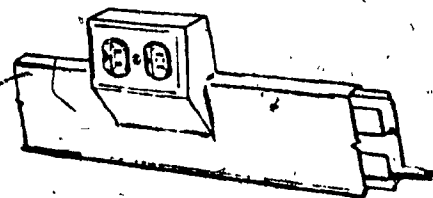
Fig. 52- Plastic Baseboard
Raceway and Recep-
tacle Cover
(Ref. 31)

CLOSED KITCHEN MODULE
FOR TRANSPORTATION

INPLACE KITCHEN MODULE

Range
Hood
Duct

Refrigerator

Appliance
Wall

Range Hood

Range

Back Wall-2x4
Wood Framing

Appliance
Wall

Modules are pushed together
for shipment
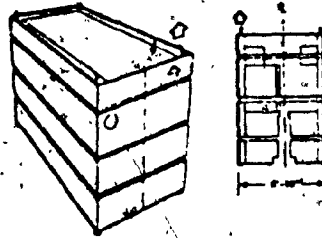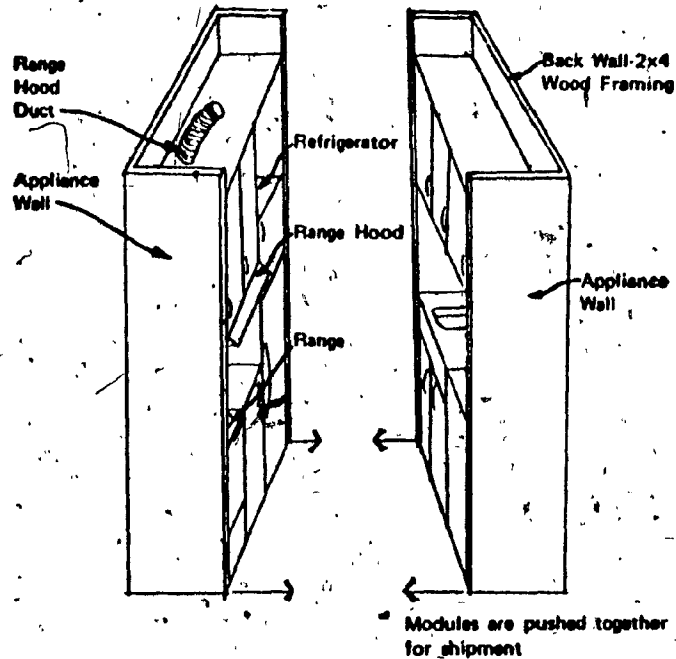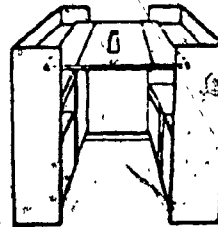
Fig. 53- Rouse-Wates; Kitchen Module
(Ref. 32)

3.1.7 Shelley System

1. <u>General</u>. The principle innovative feature of Shelley System is the use of precast three-dimensional box-module made of concrete. These boxes are stacked in a vertical checkerboard pattern. The open space created become usable living areas. The created space are completed by precast roof closure panels, Figure 54.

The flexibility of Shelley System is limited. It is applicable to all multi-family apartment, hotels, motels, hospitals, nursing homes and dormitories. It can vary from 2 to 35 stories in height. It is adaptable to all localities, climatic and topographical conditions. It is especially suitable for use in areas susceptible to hurricane, winds and earthquakes, including seismic zone 3.

The Shelley System has the highest degree of industrialization. Items that are totally installed within the precast box module at the factory include: exterior walls, spandrels and windows, interior walls and doors, partitions, kitchens, bathrooms, balconies with railings, painting, flooring, vertical piping and ductwork, and closets and storage walls. Items that are installed within the created area include: exterior wall panels, spandrel and window panels, interior wall panels and closet and storage components.

Foundations, elevator installations, landscaping, grading, roofing, flashing and water roofing is all

completed conventionally at the site. Figures 55 and 56 illustrates different profiles of Shelley System.

2. Structure. Factory-produced concrete box modules are stacked one upon another in a checkerboard pathern. Boxes overlap provide complete vertical matching for the columns which carry all gravity loads to the foundation. Walls are designed to be non-load bearing. In case of progressive collapse, an abnormal loading within a module could cause failure of walls, floor and ceiling enclosing ther space but the columns and beams would remain in place. Figure 57.

2.1 Joints. The columns contain vertical ducts in which steel dowels are grouted to provide structural continuity connect the boxes vertically from roof to footing. Bearing pad can be either neoprene, steel plate with grout or a neoprene-steel sandwich, depending on design conditions. The neoprene bearing pad provides the additional benefit of sound attenuation between modules. Figure 58.

3. Mechanical System. The mechanical utility shafts are run vertically inside the concrete box module. The Shelley System provides direct line heating and cooling without the need of costly duct branch line. It is adaptable to all standard HVAC systems. Plumbing may be installed conventionally at the site, if necessary.

4. Electrical System. All conduits and outlets for power, telephone, television and intercom are integrated within the pre-manufactured concrete box-module.

5. Kitchen and Bathroom. Kitchen and bathroom are completely installed within the precast concrete box-module. Occasionally, for total flexibility, components of kitchens and bathrooms are brought to the site out of the precast box-module.

6. Transportation and Erection. A large crane was utilized by Shelley System, within the plant, for transfer of the completed concrete modules from the assembly line to the curing/storage yard. Figure 59. It was also used for loading the module onto the highway transporter.

The highway transporter utilized was a special purpose 60-tons capacity drop-bed trailer which measured 36 inches high, 10 ft wide and 53 ft long. This dual axle, 16 tire (1000 x 15-14 ply) heavy-duty transporter required a special double-transmission tractor to haul the modules, the largest of which weighed 53 tons. Police escort were also required to block traffic at intersections and to permit continuous movement without interruption. The precast concrete end panels were transported on flat-bed trailer with special "A" frames.

Because the system was entirely of concrete, no special protective packaging was provided during yard

storage or the highway transportation.

Economical transportation range was up to a distance of 200 miles.

On site erection was accomplished by cranes with lifting capacity of upto 120 tons.
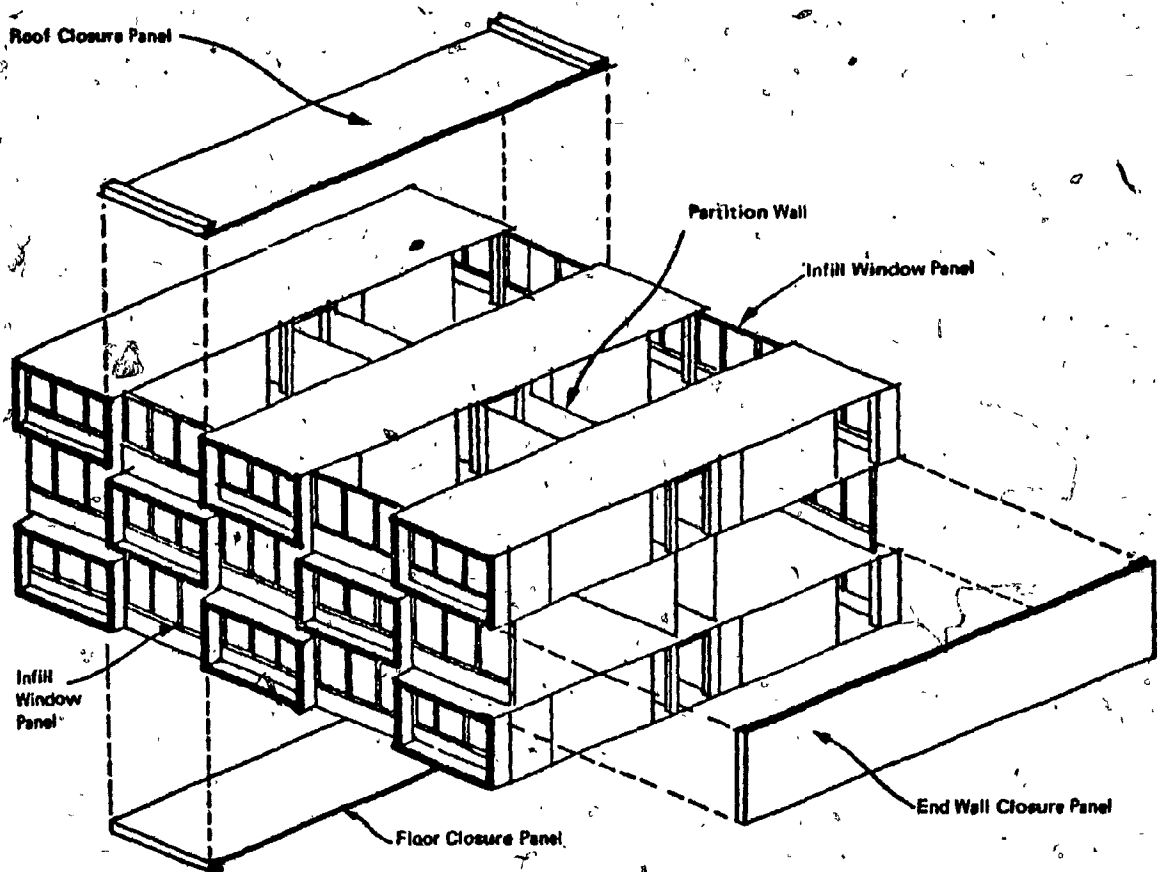
Fig. 54- Checkerboard arrangement of modules and completion of structural assembly (Ref. 32)
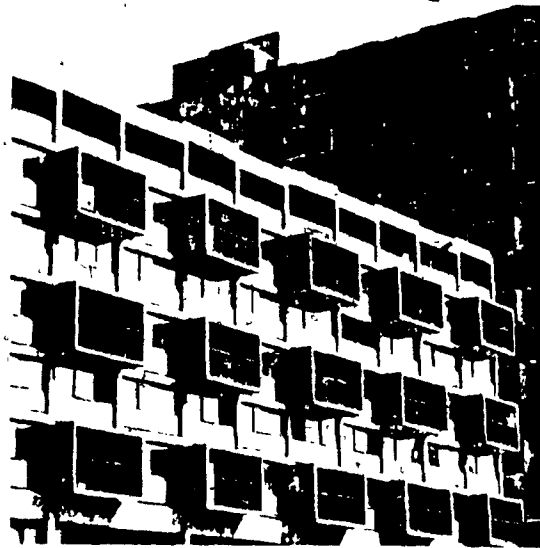
Fig. 55- Two Shelley High-Rises
(Ref. 34)
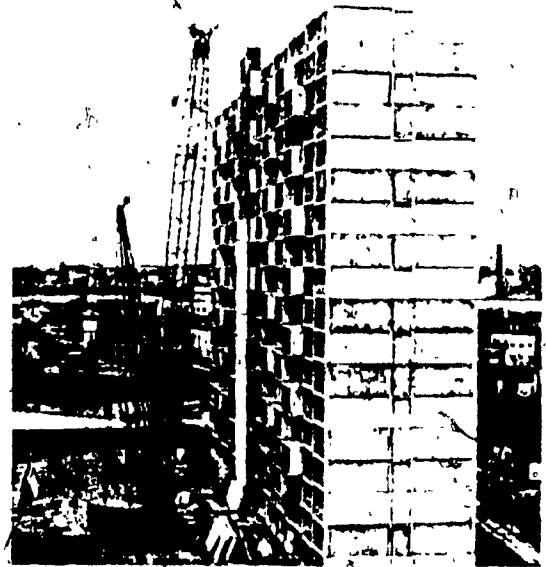
Fig. 56- Shelley A Topping Out
(Ref. 34)
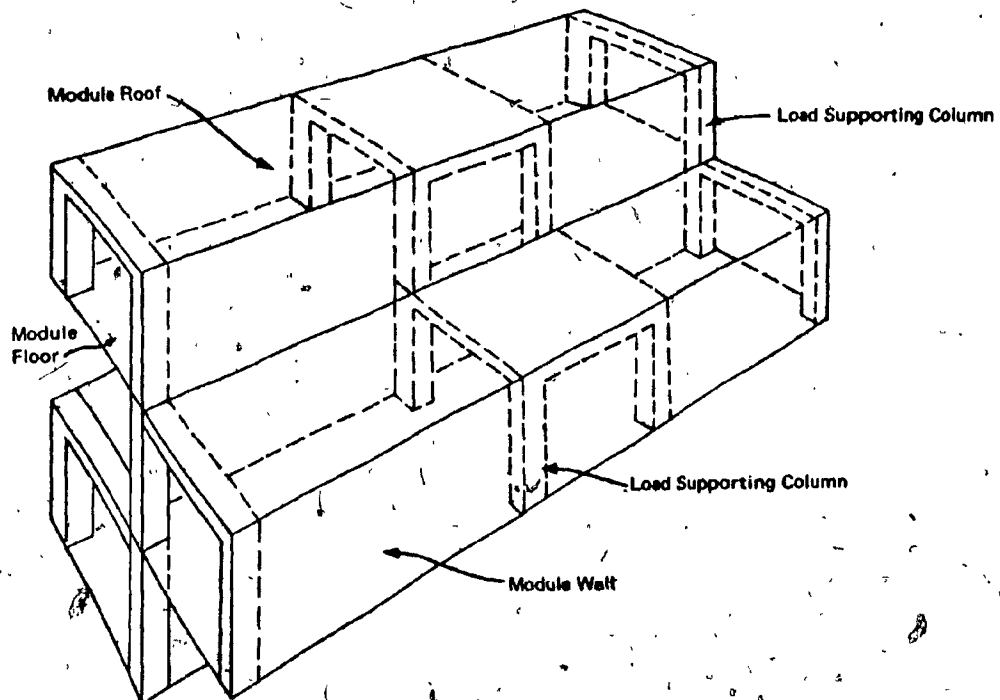
Fig. 57- Shelley; Vertical Alignment of Module Columns
(Ref. 32)
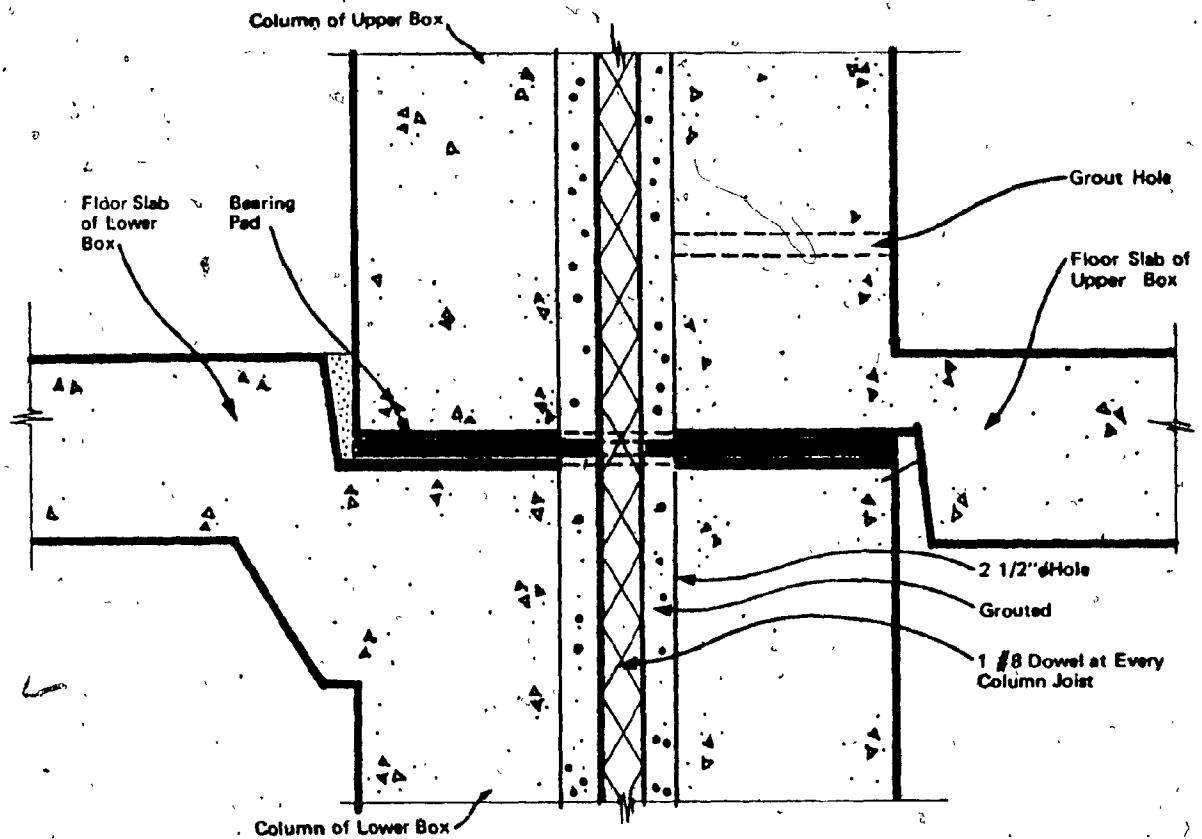
Fig. 58- Shelley; Typical Column to Column Joint
(Ref. 32)
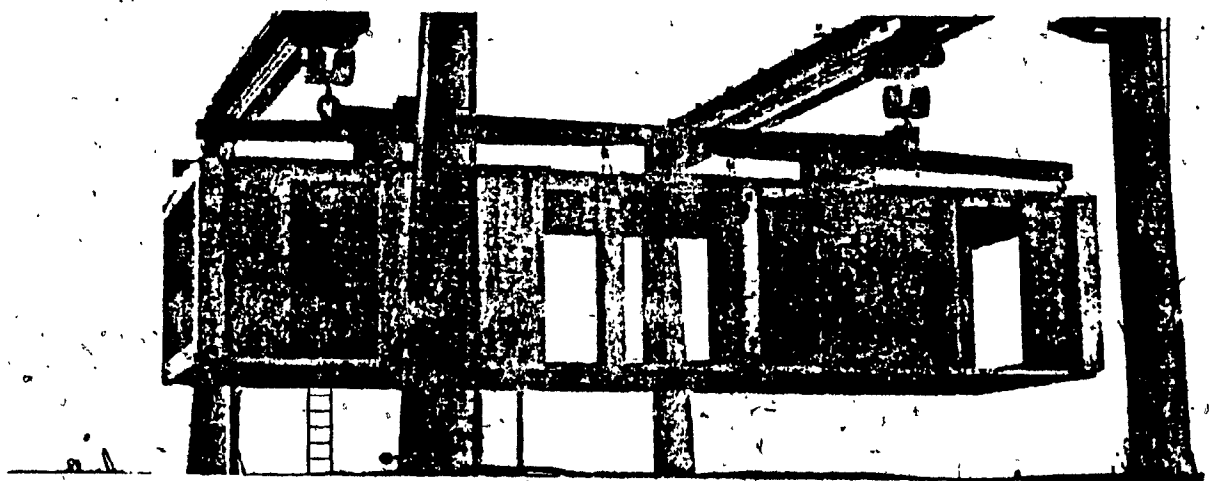
Fig. 59- Bridge-Crane used to carry Box-Module
(Ref. 33)

3.2 Comparative Summary Analysis of Industrialized
Housing Systems

The following matrices are the comparative summary analysis of the seven proposed high density industrialized housing systems with respect to the specified criteria, i.e., system design and applicability, building systems, building subsystems, production, economics of system, and management and organization.

Due to the space limitation the following glossary of terms are to be used:

Conven : Conventional

Eff : Effeciency

LB : Load Bearing

MFLR : Multi-Family Low Rise

MFMR : Multi-Family Meduim Rise

MFHR : Multi-Family High Rise

NLB : Non-Load Bearing

PCC : Pre-Cast Concrete

R : Rural

RH : Radiant Heating

S : Suburban

SFD : Single Family Detached

SFA : Single Family Attached

U : Urban

UR : Urban Renewal

3.2.1 - Comparative Summary Analysis of Housing Systems vs. System Design & Applicability.

Housing Systems / Criteria	B.S.I.	Camci	Componoform	Descon Concordia	FCE Dillon	Rouse Wates	Shelley
1. Location	U, S, UR	Urban	U, S, UR New towns	U, S, UR	U, S, UR	U, S, UR, R New towns	Urban
2. Density Range	10 to 150 Unit/acre	250/acre	250/acre	20 to 200 Per acre	4 to 70 Per acre	33 or More Per acre	8 to 220 Per acre
3. Environmental Adaptability	All climate topography, soil	All climate topography, soil	All climate topography, soil	All climate topography, soil	All climate topography, upto 12 degree slopes, soil	All climate topography, soil	All climate topography, soil
4. Codes Adaptability	All national except conduits system	All national	All national	All national	All national	All national	All national
5. Non-residential Functions	Recreation facilities	1st floor (s) office	Office, school, hospital commercial	Recreational social and commercial	Recreational social and commercial	Recreational office schools, hospitals	Dormitories hotels motels hospitals
6. Site planning services	Consultants or producer	Wide range from staff	Consultants & producer	By proposer	Consortium member	By proposer	Joint venture
7. Architectural Flexibility	High	Variety possible	Very high	Very high	Variety possible	High	Limited
8. Major Innovative Concepts	Deck-house with recreation areas; embedded electrical conduit	Balcony	Structural framing elements	Pipeless plumbing wall, balconie & sun deck, dry bolted joints.	Heart module elevator module	Special jointing system	Box module

3.2.2 - Comparative Summary Analysis of Housing Systems v.s. Building Systems.

Housing Systems / Criteria	B.S.I.	Camcl	Compono-form	Descon Concordia	FCE dillon	Rouse wates	Shelley
1. Types of System	Open	Open	Open	Open	Semi-open	Open	Closed
2. Plant Required	Yes	Yes	Yes	No	Yes	Yes	Yes
3. Housing Type	SFD SFA MFLR MFMR MFHR	MFMR MFHR MFLR under certain conditions	SFA MPLR MFMR MFHR	MFLR MFMR MFHR	SFA MFLR MFMR MFHR	MFLR MFMR MFHR	SFD SFA MFLR MFMR MFHR
4. Unit Variation	Eff. 1 to 5 bedrooms	Eff. 1 to 6 bedrooms	Eff. 1 to 5 bedrooms	Eff. 1 to 5 bedrooms	Eff. 1 to 6 bedrooms	Eff. 1 to 6 bedrooms	Eff. 1 to 6 bedrooms

3.2.3 - Comparative Summary Analysis of Housing Systems vs. Building Subsystems.

Housing Systems / Criteria	B.S.I.	Camci	Compono-form	Descon Concordia	FCE dillon	Bouse wates	Shelley
1. Structure	P.C.C. panels	P.C.C. panels	P.C.C. columns and beams	P.C.C. panels and beams	P.C.C. panels, wood frame	P.C.C. panels	P.C.C. box-modules
2. Exterior Elements	Balconies deck sections	Balconies NLB facades	Balconies frames	Balconies and sundeck	Wood frame infill panels	P.C.C. or wood frame NLP walls	Balconies corridors, bridges
3. Interior Elements	P.C.C. panels partitions	LB panels and NLB partitions	NLB partitions	Light weight concrete partitions	Wood frame partitions, convent. finishes	Precast or build-up partitions	Convent. interior spaces
4. Foundation	Convent.	Convent.	Convent.	Convent.	Convent	Convent.	Convent.
5. HVAC	RH integrated or unit cooling	Convent.	Integrated in the system	Integrated in the system	Integrated in the panels	Convent.or individual package	Integrated within the modules
6. Plumbing	Integrated in panels	Convent.	Run vertically in structural slabs	Integrated in panels	Convent. integrated in the panels	Integrated in panels	Integrated in convent. modules
7. Electrical	Conduits cast in panels	Conduits cast in panels	Conduits in grooves or under floor race ways	Prefabricated in the surface race ways	Convent. integrated in the panels	PVC base-board race ways	integrated in precast box-modules

3.2.4 - Comparative Summary Analysis of Housing System vs. Production.

Housing Systems / Criteria	B.S.I.	Camci	Compono-form	Descon Concordia	FCE dillon	Rouse wates	Shelley
1. Off-site Production	Panels, slabs, service sub-systems	Panels, slabs, service sub-systems	Columns beams, slabs service sub-systems	Panels, slabs, beams sub-systems	Panels, wood frame & roof-trusses sub-systems	Panels, partitions services sub-systems	Box-module closed-up service sub-systems
2. On-site production	Optional mechanical services	Mechanical services	If feasible on-site factory	Optional PCC panels & assembly of components	Concrete wall & floor panel if economical	Optional partition, wall & roof panels	Possible on-site plant
3. On-site Construction	Foundation assemblies connections finishes	Foundation assemblies connections finishes	Foundation assemblies connections finishes	Foundation assemblies connections optional finishes	Foundation assemblies connections finishes	Foundation assemblies connection finishes	Foundation assemblies connections finishes
4. Labor	Unskilled skilled	Unskilled semi-skilled	Unskilled skilled	Minimum on-site skilled	Skilled semi-skilled	Skilled semi-skilled unskilled	Skilled semi-skilled
5. Labor Training	On-the-job training	Trained in production operation	On-the-job training	In construction management & manufacturing	Apprentice training	On-the-job training	Unskilled training program

1.3.8   System adaptability to new technology as they develop.

1.3.9   Ease in implementing new technologies.

1.4. SERVICEABILITY

1.4.1   Contributes to basic needs for shelter, safety, and security.

1.4.2   Meets all regulatory health, safety, and sanitary requirements.

1.4.3   Interior finishes durability under service conditions.

1.4.4   Exterior finishes durability under service conditions and climatic extremes.

1.4.5   Minimum building damage induced by material volume changes and distortion.

1.4.6   Minimum material deterioration due to condensation.

1.4.7   Limitation of interior and exterior material combustibility.

1.4.8   Durability of structure, materials, and connections under repeated and cyclical service loads.

1.4.9   Annual maintenance cost reduction resulting in long-term cost saving.

1.5 SUB-SYSTEMS

1.5.1   Subsystems applicability.

1.5.2   Integration of environmental control subsytems.

1.5.3   Integration of solid and fluid waste disposal subsystems.

1.5.4   Integration of utility service subsystems.

1.5.5   Decentralization of mechanical and electrical

subsystems.

1.5.6 Inherent sound attenuation characteristics.

1.5.7 Inherent fire separation characteristics.

1.5.8 Unimpairment of structural integrity from subsystem installation.

1.5.9 Prefabrication of subsytems by another manufacturer.

2. PRODUCTION

2.1 FACILITIES

2.1.1 Off-site prefabrication and assembly.

2.1.2 On-site prefabrication and assembly.

2.1.3 Off-site prefabrication and on-site assembly.

2.1.4 Central plant capable of serving wide geographical market area.

2.1.5 Capability of having temporary plants on-site.

2.1.6 Efficient plant layout.

2.1.7 Capability of mass production.

2.1.8 Plant location ease design restriction imposed by transportation regulations.

2.1.9 Independent of construction season weather cycles.

2.2 ASSEMBLY

2.2.1 Capability of transferring traditional ways of constuction from the field into factory.

2.2.2 Employment of flow-line techniques.

2.2.3 Standardization without seriously limiting design freedom.

2.2.4 Opportunities for systematic integration of innovative technology into construction.

2.2.5 Maximum factory finishing.

2.2.6 Assembly tolerances accuracy minimizes subsequent construction problems.

2.2.7 Advantageous utilization of materials not feasible in conventional construction.

2.2.8 Assurance of quality control through inspection procedures.

2.3 LABOR

2.3.1 Compatable to existing industry and construction labor-force.

2.3.2 Central control and coordination of various construction crafts.

2.3.3 Factory work cycles meet on-site construction requirements.

2.3.4 Enable to employ unskilled labor in plant.

2.3.5 Provision for union labor collective bargaining.

2.3.6 Local employment and training opportunities.

2.3.7 Potential for occupant 'sweat equity'.

2.3.8 Productivity of workers through performance of repetitive tasks.

2.4 PROCESS

2.4.1 Level production scheduling.

2.4.2 Production capacity meets local market demands.

2.4.3 Production coordination with on- site preparation.

2.4.4 Effective material procurement.

2.4.5 Consistant supply support.

2.4.6 Sufficient raw material inventory.

2.4.7 Minimization of lead time for delivery.

2.4.8 Increasing productivity during operational
learning phase.

2.4.9 Stable productivity during routin-acquring phase.

2.4.10 Change of models require minimum start-up time
and retooling time.

2.4.11 Change of production line requires minimum
additional costs.

3.   TRANSPORTATION AND ERECTION

3.1 MOBILITY

3.1.1 Capability of housing system movement by highway,
rail, water, and air.

3.1.2 Transport accessibility unrestricted by locality
of plants and building sites.

3.1.3 Direct transportation in a single mode from the
plant to the building site.

3.1.4 Transportation feasibility to scattered sites.

3.1.5 Minimum transportation damage potential.

3.1.6 Minimum vandalism potential.

3.1.7 Minimum dimension constraints imposed by transport
mode.

3.1.8 Minimum requirement for packaging.

3.1.9 Minimum weight constraints imposed by transport
mode.

3.1.10 Limitation of transportation staging area at plant
and at site.

3.2 TRANSPORT ECONOMICS

3.2.1 Minimum transportation cost per square foot of

building floor area.

3.2.2 Maximum building floor area transportable with one carrier.

3.2.3 Optimum transportation range.

3.2.4 Additional variable transportation costs.

3.2.5 Minimum required transportation scheduling.

3.2.6 Expedient transportation time

3.2.7 Transportation does not require excessive structural rigidity and integrity.

3.2.8 Availability of sufficient carriers maintain a constant transportation flow.

3.2.9 Transportation equipments require low capital investment.

3.3 ERECTION PROCEDURE

3.3.1 Applicable on scattered sites.

3.3.2 Limited consideration required for utility service lines and poles.

3.3.3 Building system is adaptable to variety of erection procedure.

3.3.4 Minimum requirements for site preparation.

3.3.5 Minimum topographical constraints.

3.3.6 Maximum daily emplacement rate.

3.3.7 Erection equipment required minimum capital investment.

3.3.8 Maintenance cost of equipment activeness is minimum.

3.3.9 Maneuverability of erection equipment.

3.3.10 Close-tolerance connections minimizes difficulties.

4. MARKETING

4.1 APPLICABILITY

4.1.1 Applicable for urban and urban-fringe housing market.

4.1.2 Applicable for dormitory, motel, hotel, nursing home, geriatric, military and similar housing sub-markets.

4.1.3 Applicable for educational, commercial, and industrial building type-markets.

4.1.4 Applicable to both private and public sectors of housing market.

4.1.5 Applicable in urban renewal projects with minimum dislocation time and disturbance to neighbourhood.

4.1.6 Applicable to repair of individual dwelling and to rehabilitation.

4.2 DISTRIBUTION

4.2.1 Organized plan to assure a stable demand and steady consumption of production.

4.2.2 Market absorption rate is sufficient to justify capital investment in plant and equipment. Assume public housing demand is sufficient to permit production of a minimum of 250 units per year, per region for a period of 5 years.

4.2.3 System capable of being produced under license in other market areas.

4.2.4 Distributable to any qualified builder-developer.

4.2.5 Distributable to franchise dealer-erectors.

4.2.6 Potential for volume sales.

4.2.7 Optimum market radius from the plant.

4.3 ACCEPTABILITY

4.3.1 Acceptability of design with respect to consumer preference. -

4.3.2 Acceptability of architectural appearance with expectations of consuming public.

4.3.3 Psychological comfort through use of building materials.

4.3.4 Creates acceptable image in mind of consuming public

4.3.5 Acceptance by design professions.

4.3.6 Acceptance by traditional skilled costruction trade unions.

4.3.7 Acceptance by lending institutions, public regulatory agencies, and insurance companies.

4.3.8 Acceptance by national model building codes.

4.3.9 Acceptance by state-regulated industrial building codes.

4.3.10 Competitive with conventional construction systems in market area.

4.4 FLEXIBILITY

4.4.1 Rapid response towards higher densities housing.

4.4.2 Models flexibilities satisfy spectrum of local market, in particular, capacity for low-rise housing.

4.4.3 Models variations, not under four stories high, with competitive dwelling unit costs.

4.4.4 Model changes require minimum overhead costs.

4.4.5 System capable of more than one concurrent construction project at different locations.

5. FINANCING

5.1 INVESTMENT

5.1.1 Requirement of capital investment for design and development of system. ———

5.1.2 Requirement of capital investment for the plant.

5.1.3 Availability and reliability sources of required capital investment.

5.1.4 Minimum commitment of production facility to long-term amortization of high-cost equipment.

5.1.5 Expected return of capital through rapid sales.

5.1.6 Market able to bear the capital recovery changes necessary for the required rate of return on investment, assuming public housing demand of 250 units per year.

5.1.7 Depending on public housing demand of 250 units/ year, the low overall cost of construction correlates with a reasonable profit return.

5.2 OPERATION

5.2.1 Sufficient working capital to operate plant.

5.2.2 Introduction and application of the system requires minimum expenditures.

5.2.3 System administration is allied with well financed cooperative organizations.

5.2.4 Operation of system is an extension of parent corporation.

5.2.5 Operation of system is diversified activity of parent corporation.

5.3 COSTS

5.3.1 Reduction of direct costs of materials through

savings in volume purchasing, reduced waste, reduced theft and vandalism and refined design.

5.3.2 Reduction of direct labor costs through industrial labor wage differential.

5.3.3 Reduction of unit labor costs through increasing productivity.

5.3.4 Economies of industrialized assembly process offset the add-on-costs of transportation and erection.

5.3.5 Real estate tax reduction due to shortened total development time.

5.3.6 Saving in short-term financing costs due to shortened total development time.

5.3.7 Possibility of cost reduction without parallel reduction of quality standards.

6. ORGANIZATION

6.1 SERVICES

6.1.1 Organization has design and technological experties.

6.1.2 Organization has production capability.

6.1.3 Organization has transportation and erection capability.

6.1.4 Organization has on-site construction capability.

6.1.5 Organization has real estate and marketing sales force.

6.1.6 Organization has financial and legal experties.

6.1.7 Organization has land acquisition and development capability.

6.2 SCOPE

6.2.1 The entire construction-development process is dominated by unity of organizational control.

6.2.2 Capability of organization to generate its own market.

6.2.3 Capability of organization to perform market analyses and feasibility studies.

6.2.4 Organization functions as holding company with capability of rendering services by subsidary units.

6.2.5 Provision for feedback of information within organization regarding experience in design, production, transportation, erection, and distribution.

6.2.6 Organization conducts post-construction evaluation of product and market.

The key word is taken from each of the above criterion in the following matrices.

4.3 Evaluation Matrices*

The evaluation matrix serves as a valuable tool for both subjective and objective evaluation of various alternative problem solutions. These alternative solutions are evaluated with respect to their capabili-

---

* "Project Breif System, User Manual", Public Works of Canada, Ottawa, September 1976.

ties to satisfy certain predetermined discrete criteria.

Judgments are expressed by numerical ratings which are processed through successive levels of criteria into a single value for each solution. This value is a non-dimensional number having no other significance than its relativity to the values of other solutions. The final decision as to the selection of the "best" solution may for political or other reasons, ignore the process. However, selecting any solution but the mathematically "best one", requires justification and a recognition of potential consequences.

Evaluation Organization. The most critical aspect of the evaluation process is the initial weighting of the sever criteria categories. Sensitivity analyses of final results can often indicate major changes with only minor changes to relative weightings. Because of the importance of this weighting process, it is essential that only competent professionals representing the total spectrum of necessary disciplinary inputs, be employed in the process. This evaluation team should have the authority and knowledge to establish these first weightings and then make final evaluations in the light of sensitivity analyses after ratings by others are completed in each criteria category.

The process of weighting is generally carried out in an open forum with the evaluation team,

and special consultant present the moderator or chairman
will seek consensus in each item rather than averaging
opinions, thus avoiding a "numbers game". It is important
that the team is convinced by the specialists of each
relative weighting.

Following the weighting process, separate team of
experts in each specific criteria category are formed to
rate and sometimes even weight lower levels of criteria.
The rating of the lowest level of criteria triggers the
results of each subsequent higher level automatically.

In the case of this report, expert inputs were
limited, and therefore, the final results should be treated
as a guideline only in the selection of existing industria-
lized building systems.

Procedures. The following steps are to be carried
out for the use of Evaluation Matrices:

STEP 1. The first entries are judgments of the relative
importance of criteria within mutually-related
groups at the respective levels, called criteria
weight constants (C_n), and entered at all three
levels and are maintained throughout the entire
evaluation of alternative systems. However, it is
expected that the criteria weight constants will
be modified with passage of time and change of
location. The criteria weight constants are an
indication of the relative importance of the criteria
and are not to be influenced by or altered for specific
systems. The weighting assignment of the constants are

made by allocation, with the sum totalling
100 in each of the mutually related groups.

STEP 2. The second input data, to be entered at Level 3
only (the last level), are the quantitative
assignments of values within the mutually related
groups of criteria to indicate how effectively
a specific housing system can potentially satisfy
those criteria. These merit values or ratings
(R_n) are assigned by the decision-maker for
each criterion on a scale in which

$$0.00 \leq R_n \leq 1.00$$

Unlike the criteria weight assingments (C_n),
which are constants for all systems, the rating
values (R_n) are variable and will differ in the
evaluating of alternative systems.

STEP 3. Now in processing the data entered in the
matrices, we have to calculate the value (V) for
each Level 3 criterion, that is the product of
criteria weight constant for a given criteria
and the corresponding variable rating value
expressed as follows:

$$V = C_n R_n$$

STEP 4. Add all the values (V) for each of mutually
related groups of criterion in Level 3 to

provide a total value (T_n) expressed as follows:

$$T_n = \sum V = \sum C_n R_n$$

STEP 5. Move to the next higher level (Level 2) of criteria, enter the total value (T_n) from Level 3 as the "Rating" for the related corresponding criterion.

Note: The total value for each of mutually related groups of criterion is divided by 100 (total criteria weight constant) in order to find the "Rating" for the next higher related corresponding criterion.

STEP 6. Repeat step 3, 4, and 5. This is repeated at each level until the final totals are calculated at the highest level (Level 1) matrix to provide a numerical comparison for evaluation of each alternative housing systems.

4.4 Application

The evaluation of the seven proposed high density industrialized housing systems with respect to the pre-established technological and economical performance criteria are carried out in the following matrices.

The assignment of the criteria weightings and the ratings have been based on the availability of

Level 1. Evaluation Matrix - Overall Performance Effectiveness; Selection of Industrialized Housing Systems

HOUSING SYSTEMS / CRITERIA	CRITERIA WEIGHT C_n	B.S.I. RATING R_n	B.S.I. VALUE V	B.S.I. T.VALUE T_n	CAMCI RATING R_n	CAMCI VALUE V	CAMCI T.VALUE T_n	COMPO-NOFORM RATING R_n	COMPO-NOFORM VALUE V	COMPO-NOFORM T.VALUE T_n	DESCON CONCORDIA RATING R_n	DESCON CONCORDIA VALUE V	DESCON CONCORDIA T.VALUE T_n	FGE-DILLON RATING R_n	FGE-DILLON VALUE V	FGE-DILLON T.VALUE T_n	ROUSE WATES RATING R_n	ROUSE WATES VALUE V	ROUSE WATES T.VALUE T_n	SHELLEY RATING R_n	SHELLEY VALUE V	SHELLEY T.VALUE T_n
Overall Performance Effectiveness																						
1. DESIGN	18	.79	14.2		.72	13		.83	14.9		.85	15.3		.77	13.9		.77	13.9		.68	12.2	
2. PRODUCTION	18	.80	14.4		.77	13.9		.81	14.6		.82	14.8		.77	13.9		.76	13.7		.76	13.7	
3. TRANSPORTATION AND ERECTION	12	.79	9.5		.79	9.5		.79	9.5		.81	9.7		.76	9.1		.79	9.5		.57	6.8	
4. MARKETING	15	.78	11.7		.72	10.8		.83	12.5		.86	12.9		.80	12		.77	11.6		.65	9.8	
5. FINANCING	22	.82	18		.81	17.8		.83	18.3		.88	19.4		.84	18.6		1.84	17.8		.76	16.7	
6. ORGANIZATION	15	.77	11.6		.82	12.3		.73	11		.79	11.9		.84	12.6		.78	11.7		.80	12	
TOTAL	100			79.4			79.3			80.8			84			80			78.2			71.2

Level 2. Evaluation Matrix - Design

HOUSING SYSTEMS / CRITERIA	CRITERIA WEIGHT G_n	B.S.I. RATING R_n	B.S.I. VALUE V	B.S.I. T.VALUE T_n	CAMCI RATING R_n	CAMCI VALUE V	CAMCI T.VALUE T_n	COMPO-NOFORM RATING R_n	COMPO-NOFORM VALUE V	COMPO-NOFORM T.VALUE T_n	DESCON CONCORDIA RATING R_n	DESCON CONCORDIA VALUE V	DESCON CONCORDIA T.VALUE T_n	PCB DILLON RATING R_n	PCB DILLON VALUE V	PCB DILLON T.VALUE T_n	ROUSE WATES RATING R_n	ROUSE WATES VALUE V	ROUSE WATES T.VALUE T_n	SHELLEY RATING R_n	SHELLEY VALUE V	SHELLEY T.VALUE T_n
1. DESIGN																						
1.1 PLANNING	15	.88	13.2		.88	13.2		.91	13.7		.94	14.1		.87	13.1		.89	13.4		.81	12.2	
1.2 STRUCTRURE	30	.81	24.3		.78	23.4		.87	26.1		.87	26.1		.78	23.4		.79	23.7		.59	17.1	
1.3 ADAPTIBILITY	15	.62	9.3		.44	6.6		.64	9.6		.69	10.4		.59	8.9		.58	8.7		.49	7.4	
1.4 SERVICEABILITY	25	.80	20		.76	19		.84	21		.87	21.8		.78	19.5		.77	19.3		.78	19.5	
1.5 SUB-SYSTEM	15	.80	12		.65	9.8		.83	12.5		.85	12.8		.81	12.2		.78	11.7		.77	11.6	
TOTAL	100			78.8			72			82.9			85.2			77.1			76.8			67.8

Level 2. Evaluation Matrix - Production

HOUSING SYSTEMS / CRITERIA	CRITERIA WEIGHT C_n	B.S.I. RATING R_n	B.S.I. VALUE V	B.S.I. T.VALUE T_n	CAMCI RATING R_n	CAMCI VALUE V	CAMCI T.VALUE T_n	COMPO-NOFORM RATING R_n	COMPO-NOFORM VALUE V	COMPO-NOFORM T.VALUE T_n	DESCON CONCORDIA RATING R_n	DESCON CONCORDIA VALUE V	DESCON CONCORDIA T.VALUE T_n	PCE DILLON RATING R_n	PCE DILLON VALUE V	PCE DILLON T.VALUE T_n	ROUSE WATES RATING R_n	ROUSE WATES VALUE V	ROUSE WATES T.VALUE T_n	SHELLEY RATING R_n	SHELLEY VALUE V	SHELLEY T.VALUE T_n
2. PRODUCTION																						
2.1 FACILITIES	25	.79	19.8		.78	19.5		.78	19.5		.78	19.5		.73	18.3		.72	18		.73	18.3	
2.2 ASSEMBLY	25	.83	20.8		.79	19.8		.85	21.3		.81	21.8		.81	20.3		.81	20.3		.77	19.3	
2.3 LABOR	20	.78	15.6		.74	14.8		.78	15.6		.78	15.6		.75	15		.76	15.2		.77	15.4	
2.4 PROCESS	30	.79	23.7		.76	22.8		.81	24.3		.85	25.5		.78	23.4		.76	22.8		.75	22.5	
TOTAL	100			79.9			76.9			84.7			82.4			77			76.3			75.5

Level 2. Evaluation Matrix - Transportation and Erection

HOUSING SYSTEMS / CRITERIA		CRITERIA WEIGHT C_n	B.S.I.			GAMCI			COMPO-NOFORM			DESCON CONCORDIA			FCE DILLON			ROUSE WATES			SHELLEY		
			RATING R_n	VALUE V	T.VALUE T_n	RATING R_n	VALUE V	T.VALUE T_n	RATING R_n	VALUE V	T.VALUE T_n	RATING R_n	VALUE V	T.VALUE T_n	RATING R_n	VALUE V	T.VALUE T_n	RATING R_n	VALUE V	T.VALUE T_n	RATING R_n	VALUE V	T.VALUE T_n
3. TRANSPORTATION AND ERECTION																							
3.1 MOBILITY		30	.79	23.7		.79	23.7		.80	24		.81	24.3		.75	22.5		.78	23.4		.61	18.3	
3.2 TRANSPORTATION ECONOMICS		40	.79	31.6		.80	32		.77	30.8		.81	32.4		.77	30.8		.80	32		.56	22.4	
3.3 PROCEDURES		30	.80	24		.78	23.4		.79	23.7		.81	24.3		.76	22.8		.78	23.4		.53	15.9	
TOTAL		100			79.3			79.1			78.5			81			76.1			78.8			56.6

Level 2. Evalation Matrix - Marketing

HOUSING SYSTEMS / CRITERIA	CRITERIA WEIGHT C_n	B.S.I. RATING R_n	B.S.I. VALUE V	B.S.I. T.VALUE T_n	GAMCI RATING R_n	GAMCI VALUE V	GAMCI T.VALUE T_n	COMPO-NOFORM. RATING R_n	COMPO-NOFORM. VALUE V	COMPO-NOFORM. T.VALUE T_n	DESCON CONCORDIA RATING R_n	DESCON CONCORDIA VALUE V	DESCON CONCORDIA T.VALUE T_n	FCE DILLON RATING R_n	FCE DILLON VALUE V	FCE DILLON T.VALUE T_n	ROUSE WATES RATING R_n	ROUSE WATES VALUE V	ROUSE WATES T.VALUE T_n	SHELLEY RATING R_n	SHELLEY VALUE V	SHELLEY T.VALUE T_n
4. MARKETING																						
4.1 APPLICABILITY	15	.62	9.3		.46	6.9		.88	13.2		.75	11.3		.72	10.8		.77	11.6		.59	8.9	
4.2 DISTRIBUTION	30	.72	21.6		.70	21		.74	22.2		.85	25.5		.80	24		.67	20.1		.55	16.5	
4.3 ACCEPTABILITY	35	.85	29.8		.84	29.4		.87	30.5		.89	31.2		.85	29.8		.83	29.1		.75	26.3	
4.4 FLEXIBILITY	20	.85	17		.72	14.4		.86	17.2		.89	17.8		.79	15.8		.79	15.8		.64	12.8	
TOTAL	100			77.7			71.7			83.1			85.6			80.4			78.6			64.5

Level 2. Evaluation Matrix - Financing

HOUSING SYSTEMS / CRITERIA	CRITERIA WEIGHT G_n	B.S.I. RATING R_n	B.S.I. VALUE V	B.S.I. T.VALUE T_n	CAMCI RATING R_n	CAMCI VALUE V	CAMCI T.VALUE T_n	COMPO-NOFORM RATING R_n	COMPO-NOFORM VALUE V	COMPO-NOFORM T.VALUE T_n	DESCON CONCORDIA RATING R_n	DESCON CONCORDIA VALUE V	DESCON CONCORDIA T.VALUE T_n	FGE DILLON RATING R_n	FGE DILLON VALUE V	FGE DILLON T.VALUE T_n	ROUSE WATES RATING R_n	ROUSE WATES VALUE V	ROUSE WATES T.VALUE T_n	SHELLEY RATING R_n	SHELLEY VALUE V	SHELLEY T.VALUE T_n
5. FINANCING																						
5.1 INVESTMENT	35	.77	27		.76	26.6		.80	28		.89	34.2		.80	28		.76	24.6		.70	24.5	
5.2 OPERATION	25	.78	19.5		.76	19		.78	19.5		.84	21		.81	20.3		.76	19		.67	16.8	
5.3 COSTS	40	.89	35.6		.88	35.2		.88	35.2		.89	35.6		.88	35.2		.88	35.2		.86	34.4	
TOTAL	100			82.1			80.8			82.1			84.8			83.5			80.8			75.7

Level 2. Evaluation Matrix – Organization

HOUSING SYSTEMS / CRITERIA	CRITERIA WEIGHT (C_n)	B.S.I. RATING (R_n)	B.S.I. VALUE (V)	B.S.I. T.VALUE (T_n)	CAMCI RATING (R_n)	CAMCI VALUE (V)	CAMCI T.VALUE (T_n)	COMPO-NOFORM RATING (R_n)	COMPO-NOFORM VALUE (V)	COMPO-NOFORM T.VALUE (T_n)	DESCON CONCORDIA RATING (R_n)	DESCON CONCORDIA VALUE (V)	DESCON CONCORDIA T.VALUE (T_n)	PCE DILLON RATING (R_n)	PCE DILLON VALUE (V)	PCE DILLON T.VALUE (T_n)	ROUSE WATES RATING (R_n)	ROUSE WATES VALUE (V)	ROUSE WATES T.VALUE (T_n)	SHELLEY RATING (R_n)	SHELLEY VALUE (V)	SHELLEY T.VALUE (T_n)
6. ORGANIZATION																						
6.1 SERVICES	55	.8	44		.77	42.4		.77	42.4		.83	45.7		.85	46.8		.80	44		.74	40.7	
6.2 SCOPE	45	.74	33.3		.87	39.2		.67	30.2		.74	33.3		.82	36.9		.76	34.2		.87	38.2	
TOTAL	100			77.3			81.6			72.6			79			83.7			78.2			78.9

Level 3. Evaluation Matrix – Planning

HOUSING SYSTEMS / CRITERIA	CRITERIA WEIGHT C_n	B.S.I. RATING R_n	B.S.I. VALUE V	B.S.I. T.VALUE T_n	CAMCI RATING R_n	CAMCI VALUE V	CAMCI T.VALUE T_n	COMPO-NOFORM RATING R_n	COMPO-NOFORM VALUE V	COMPO-NOFORM T.VALUE T_n	DESCON CONCORDIA RATING R_n	DESCON CONCORDIA VALUE V	DESCON CONCORDIA T.VALUE T_n	FGE DILLON RATING R_n	FGE DILLON VALUE V	FGE DILLON T.VALUE T_n	ROUSE WATES RATING R_n	ROUSE WATES VALUE V	ROUSE WATES T.VALUE T_n	SHELLEY RATING R_n	SHELLEY VALUE V	SHELLEY T.VALUE T_n
1.1 PLANNING																						
1.1.1 CONDITION	10	1	10		1	10		1	10		1	10		.9	9		1	10		1	10	
1.1.2 STANDARDS	18	1	18		1	18		1	18		1	18		1	18		1	18		1	18	
1.1.3 HARMONY	9	.8	7.2		.8	7.2		.8	7.2		.9	8.1		.8	7.2		.8	7.2		.7	6.3	
1.1.4 COMMUNITY	12	.8	9.6		.8	9.6		.8	9.6		.9	10.8		.8	9.6		.8	9.6		.7	8.4	
1.1.5 NEEDS	23	.9	20.7		.9	20.7		.9	20.7		.9	20.7		.9	20.7		.9	20.7		.8	18.4	
1.1.6 DENSITIES	10	.9	9		.9	9		.9	9		1	10		.9	9		.9	9		.9	9	
1.1.7 SITES	10	.7	7		.7	7		.9	9		.9	9		.7	7		.8	8		.5	5	
1.1.8 FACILITIES	8	.8	6.4		.8	6.4		.9	7.2		.9	7.2		.8	6.4		.8	6.4		.7	5.6	
TOTAL	100			87.9			87.9			90.7			93.8			86.9			88.9			82.7

Level 3. Evaluation Matrix – Structure

HOUSING SYSTEMS / CRITERIA	CRITERIA WEIGHT C_n	B.S.I. RATING R_n	B.S.I. VALUE V	B.S.I. T.VALUE T_n	CAMCI RATING R_n	CAMCI VALUE V	CAMCI T.VALUE T_n	COMPO-NOFORM RATING R_n	COMPO-NOFORM VALUE V	COMPO-NOFORM T.VALUE T_n	DESCON CONCORDIA RATING R_n	DESCON CONCORDIA VALUE V	DESCON CONCORDIA T.VALUE T_n	PCE DILLON RATING R_n	PCE DILLON VALUE V	PCE DILLON T.VALUE T_n	ROUSE WATES RATING R_n	ROUSE WATES VALUE V	ROUSE WATES T.VALUE T_n	SHELLEY RATING R_n	SHELLEY VALUE V	SHELLEY T.VALUE T_n
1.2 STRUCTURE																						
1.2.1 PLAN	18	.8	14.4		.7	12.6		.8	14.4		.9	16.2		.7	12.6		.7	12.6		.4	7.2	
1.2.2 VARIATION	15	.8	12		.7	10.5		.9	13.5		.8	12		.8	12		.8	12		.4	6	
1.2.3 CONFIGURATION	10	.8	8		.7	7		.9	9		.8	8		.8	8		.8	8		.5	5	
1.2.4 TREATMENT	8	.8	6.4		.8	6.4		.8	6.4		.8	6.4		.8	6.4		.8	6.4		.8	6.4	
1.2.5 FREEDOM	15	.8	12		.8	12		.9	13.5		.9	13.5		.8	12		.8	12		.6	9	
1.2.6 BALANCE	12	.8	9.6		.8	9.6		.9	10.8		.9	10.8		.7	8.4		.8	9.6		.6	7.2	
1.2.7 COMPLIANCE	12	.9	10.8		.9	10.8		.9	10.8		.9	10.8		.9	10.8		.9	10.8		.8	9.6	
1.2.8 MATERIALS	10	.8	8		.9	9		.9	9		.9	9		.8	8		.8	8		.8	8	
TOTAL	100			81.2			77.9			87.4			86.7			79.2			79.4			56.8

- 112 -

Level 3. Evaluation Matrix - Adaptibility

HOUSING SYSTEMS / CRITERIA	CRITERIA WEIGHT C_n	B.S.I. RATING R_n	B.S.I. VALUE V	B.S.I. T.VALUE T_n	CAMCI RATING R_n	CAMCI VALUE V	CAMCI T.VALUE T_n	COMPO-NOFORM RATING R_n	COMPO-NOFORM VALUE V	COMPO-NOFORM T.VALUE T_n	DESCON CONCORDIA RATING R_n	DESCON CONCORDIA VALUE V	DESCON CONCORDIA T.VALUE T_n	FCA DILLON RATING R_n	FCA DILLON VALUE V	FCA DILLON T.VALUE T_n	ROUSE WATES RATING R_n	ROUSE WATES VALUE V	ROUSE WATES T.VALUE T_n	SHELLEY RATING R_n	SHELLEY VALUE V	SHELLEY T.VALUE T_n
1.3 ADAPTIBILITY																						
1.3.1 DETACHED	5	.7	3.5		.1	.5		.1	.5		.1	.5		.1	.5		.1	.5		.9	4.5	
1.3.2 ATTACHED	9	.8	7.2		.2	18		.9	8.1		.8	7.2		.8	7.2		.6	5.4		.9	8.1	
1.3.3 WALK-UP	8	.7	5.6		.7	5.6		.9	7.2		.7	5.6		.9	7.2		.7	5.6		.3	2.4	
1.3.4 HIGH-RISE	16	1	16		1	16		1	16		1	16		1	16		1	16		1	16	
1.3.5 REPLACEMENT	14	.4	5.6		.1	1.4		1.4	5.6		.5	7		.5	7		.5	7		.1	1.4	
1.3.6 COMPONENT	12	.1	1.2		.1	1.1		.3	3.6		.1	1.2		.1	1.2		.1	1.2		.1	1.2	
1.3.7 OTHER SYSTEMS	11	.4	4.4		.1	1.1		.3	3.3		.8	8.8		.2	2.2		.4	4.4		.1	1.1	
1.3.8 TECHNOLOGY	15	.7	10.5		.7	10.5		.8	12		.9	13.5		.7	10.5		.7	10.5		.6	9	
1.3.9 IMPLEMENTATION	10	.8	8		.6	6		.8	8		.9	9		.7	7		.7	7		.5	5	
TOTAL	100			62			44.1			64.3			68.8			58.6			57.6			48.7

Level 3. Evaluation Matrix - Serviceability

HOUSING SYSTEMS / CRITERIA	CRITERIA WEIGHT C_n	B.S.I.			CAMCI			COMPO-NOFORM			DESCON CONCORDIA			PCB DILLON			ROUSE WATES			SHELLEY		
		RATING R_n	VALUE V	T.VALUE T_n	RATING R_n	VALUE V	T.VALUE T_n	RATING R_n	VALUE V	T.VALUE T_n	RATING R_n	VALUE V	T.VALUE T_n	RATING R_n	VALUE V	T.VALUE T_n	RATING R_n	VALUE V	T.VALUE T_n	RATING R_n	VALUE V	T.VALUE T_n
1.4 SERVICEABILITY																						
1.4.1 BASIC NEEDS	15	1	15		1	15		1	15		1	15		1	15		1	15		1	15	
1.4.2 REGULATION	14	1	14		1	14		1	14		1	14		1	14		1	14		1	14	
1.4.3 INTERIOR	10	.7	7		.7	7		.8	8		.8	8		.7	7		.6	6		.9	9	
1.4.4 EXTERIOR	10	.8	8		.8	8		.8	8		.8	8		.8	8		.8	8		.8	8	
1.4.5 DAMAGE	7	.7	4.9		.6	4.2		.8	5.6		.8	5.6		.5	3.5		.6	4.2		.5	3.5	
1.4.6 DETERIORATION	10	.7	7		.6	6		.7	7		.7	7		.7	7		.7	7		.7	7	
1.4.7 COMBUSTIBILITY	10	.7	7		.7	7		.8	8		.8	8		.6	6		.7	7		.7	7	
1.4.8 DURABILITY	10	.6	6		.5	5		.7	7		.9	9		.6	6		.6	6		.6	6	
1.4.9 MAINTENANCE	14	.8	11.2		.7	9.8		.8	11.2		.9	12.6		.8	11.2		.7	9.8		.7	9.8	
TOTAL	100			80.1			76			83.8			87.2			77.7			77			78.3

Level 3. Evaluation Matrix – Sub-Systems

HOUSING SYSTEMS / CRITERIA — SUB-SYSTEMS	CRITERIA WEIGHT C_n	B.S.I. RATING R_n	B.S.I. VALUE V	B.S.I. T.VALUE T_n	CAMCI RATING R_n	CAMCI VALUE V	CAMCI T.VALUE T_n	COMPO-NOFORM RATING R_n	COMPO-NOFORM VALUE V	COMPO-NOFORM T.VALUE T_n	DESCON CONCORDIA RATING R_n	DESCON CONCORDIA VALUE V	DESCON CONCORDIA T.VALUE T_n	FCE DILLON RATING R_n	FCE DILLON VALUE V	FCE DILLON T.VALUE T_n	ROUSE WATES RATING R_n	ROUSE WATES VALUE V	ROUSE WATES T.VALUE T_n	SHELLEY RATING R_n	SHELLEY VALUE V	SHELLEY T.VALUE T_n
1.5.1 APPLICABILITY	12	.8	9.6		.5	6		.9	10.8		.9	10.8		.8	9.6		.8	9.6		.8	9.6	
1.5.2 ENVIRONMENT	10	.8	8		.6	6		.8	8		.8	8		.8	8		.8	8		.8	8	
1.5.3 WASTE	10	.8	8		.6	6		.8	8		.8	8		.8	8		.8	8		.8	8	
1.5.4 UTILITY	10	.8	8		.5	5		.8	8		.9	9		.9	9		.8	8		.8	8	
1.5.5 DECENTRALIZATION	8	.8	6.4		.5	4		.9	7.2		.9	7.2		.8	6.4		.6	4.8		.8	6.4	
1.5.6 SOUND	12	.7	8.4		.7	8.4		.7	8.4		.7	8.4		.7	8.4		.7	8.4		.7	8.4	
1.5.7 FIRE	14	.8	11.2		.8	11.2		.8	11.2		.8	11.2		.8	11.2		.8	11.2		.8	11.2	
1.5.8 UNIMPAIRMENT	14	.8	11.2		.8	11.2		.9	12.6		.9	12.6		.8	11.2		.8	11.2		.8	11.2	
1.5.9 SUPPLIER	10	.9	9		.7	7		.9	9		1	10		.9	9		.9	9		.6	6	
TOTAL	100			79.8			64.8			83.2			85.2			82.8			78.2			76.8

Level 3. Evaluation Matrix - Facilities

HOUSING SYSTEMS / CRITERIA	CRITERIA WEIGHT C_n	B.S.T. RATING R_n	B.S.T. VALUE V	B.S.T. T.VALUE T_n	CAMCI RATING R_n	CAMCI VALUE V	CAMCI T.VALUE T_n	COMPO-NOFORM RATING R_n	COMPO-NOFORM VALUE V	COMPO-NOFORM T.VALUE T_n	DESCON CONCORDIA RATING R_n	DESCON CONCORDIA VALUE V	DESCON CONCORDIA T.VALUE T_n	FCE DILLON RATING R_n	FCE DILLON VALUE V	FCE DILLON T.VALUE T_n	ROUSE WATES RATING R_n	ROUSE WATES VALUE V	ROUSE WATES T.VALUE T_n	SHELLEY RATING R_n	SHELLEY VALUE V	SHELLEY T.VALUE T_n
2.1 FACILITIES																						
2.1.1 OFF-SITE	12	1	12		1	12		1	12		1	12		1	12		1	12		1	12	
2.1.2 ON-SITE	10	.5	5		.6	6		.2	2		.3	3		.5	5		.2	2		.1	1	
2.1.3 OFF-SITE ON-SITE	14	1	14		.8	11.2		1	14		1	14		.8	11.2		.9	12.6		1	14	
2.1.4 CENTRAL	5	.7	3.5		.8	4		.8	4		.9	4.5		.8	4		.8	4		.5	2.5	
2.1.5 TEMPORARY	15	.5	7.5		.5	7.5		.6	9		.3	4.5		.4	6		.3	4.5		.6	9	
2.1.6 LAYOUT	10	.9	9		.9	9		.9	9		.9	9		.9	9		.9	9		.9	9	
2.1.7 MASS PRODUCTION	12	.9	10.8		.9	10.8		.9	10.8		.9	10.8		.9	10.8		.9	10.8		.9	10.8	
2.1.8 TRANSPORTATION	12	.7	8.4		.7	8.4		.7	8.4		.9	10.8		.7	8.4		.6	8.4		.5	6	
2.1.9 WEATHER	10	.9	9		.9	8		.9	9		.9	9		.7	7		.9	9		.9	9	
TOTAL	100			78.2			77.9			78.2			77.6			73.4			72.3			75.3

Level 3. Evaluation Matrix - Assembly

HOUSING SYSTEMS / CRITERIA	CRITERIA WEIGHT C_n	B.S.I.			CAMCI			COMPO-NOFORM			DESCON CONCORDIA			FCE DILLON			ROUSE WATES			SHELLEY		
2.2 ASSEMBLY		RATING R_n	VALUE V	T.VALUE T_n	RATING R_n	VALUE V	T.VALUE T_n	RATING R_n	VALUE V	T.VALUE T_n	RATING R_n	VALUE V	T.VALUE T_n	RATING R_n	VALUE V	T.VALUE T_n	RATING R_n	VALUE V	T.VALUE T_n	RATING R_n	VALUE V	T.VALUE T_n
2.2.1 TRANSFER	9	.9	8.1		.9	8.1		.9	8.1		.9	8.1		.9	8.1		.9	8.1		.9	8.1	
2.2.2 FLOW-LINE	15	.8	12		.8	12		.9	13.5		.9	13.5		.8	12		.8	12		.7	10.5	
2.2.3 STANDARDIZATION	17	.8	13.6		.7	11.9		.8	13.6		.9	15.3		.7	11.9		.7	11.9		.7	11.9	
2.2.4 PREFABRICATION	9	.9	8.1		.9	8.1		.9	8.1		.9	8.1		.9	8.1		.9	8.1		.8	7.2	
2.2.5 FINISHING	12	.7	8.4		.5	6		.8	9.6		.8	9.6		.7	8.4		.7	8.4		.8	9.6	
2.2.6 TOLERANCES	16	.8	12.8		.8	12.8		.8	12.8		.8	12.8		.8	12.8		.8	12.8		.6	9.6	
2.2.7 MATERIALS	8	.7	5.6		.7	5.6		.7	5.6		.7	5.6		.7	5.6		.7	5.6		.7	5.6	
2.2.8 QUALITY	14	1	14		1	14		1	14		1	14		1	14		1	14		1	14	
TOTAL	100			82.6			78.5			85.3			87			80.9			80.9				76.5

Level 3. Evaluation Matrix - Labor

HOUSING SYSTEMS / CRITERIA 2.3 LABOR	CRITERIA WEIGHT C_n	B.S.I. RATING R_n	B.S.I. VALUE V	B.S.I. T.VALUE T_n	CAMCI RATING R_n	CAMCI VALUE V	CAMCI T.VALUE T_n	COMPO-NOFORM RATING R_n	COMPO-NOFORM VALUE V	COMPO-NOFORM T.VALUE T_n	DESCON CONCORDIA RATING R_n	DESCON CONCORDIA VALUE V	DESCON CONCORDIA T.VALUE T_n	FCE DILLON RATING R_n	FCE DILLON VALUE V	FCE DILLON T.VALUE T_n	ROUSE WATES RATING R_n	ROUSE WATES VALUE V	ROUSE WATES T.VALUE T_n	SHELLEY RATING R_n	SHELLEY VALUE V	SHELLEY T.VALUE T_n
2.3.1 COMPATIBILITY	12	.9	10.8		.8	9.6		.9	10.8		.9	10.8		.9	10.8		.9	10.8		.8	9.6	
2.3.2 CONTROL	10	.8	8		.7	7		.8	8		.8	8		.7	7		.7	7		.8	8	
2.3.3 CYCLE	17	.8	13.6		.8	13.6		.8	13.6		.8	13.6		.8	13.6		.8	13.6		.8	13.6	
2.3.4 UNSKILLED	14	.8	11.2		.7	9.8		.8	11.2		.9	12.6		.7	9.8		.7	9.8		.9	12.6	
2.3.5 UNION	20	.7	14		.7	14		.7	14		.7	14		.7	14		.7	14		.7	14	
2.3.6 TRAINING	10	.9	9		.8	8		.9	9		.9	9		.8	8		.8	8		.9	9	
2.3.7 SWEAT EQUITY	10	.6	6		.6	6		.6	6		.4	4		.6	6		.7	7		.7	7	
2.3.8 REPETITION	7	.8	5.6		.8	5.6		.8	5.6		.8	5.6		.8	5.6		.8	5.6		.8	5.6	
TOTAL	100			78.2			73.6			78.2			77.6			74.8			75.8			77.7

Level 3. Evaluation Matrix – Process

- ·119 -

HOUSING SYSTEMS / CRITERIA	CRITERIA WEIGHT C_n	B.S.I. RATING R_n	B.S.I. VALUE V	B.S.I. T.VALUE T_n	CAMCI RATING R_n	CAMCI VALUE V	CAMCI T.VALUE T_n	COMPO-NOFORM RATING R_n	COMPO-NOFORM VALUE V	COMPO-NOFORM T.VALUE T_n	DESCON CONCORDIA RATING R_n	DESCON CONCORDIA VALUE V	DESCON CONCORDIA T.VALUE T_n	PCE DILLON RATING R_n	PCE DILLON VALUE V	PCE DILLON T.VALUE T_n	ROUSE WATES RATING R_n	ROUSE WATES VALUE V_a	ROUSE WATES T.VALUE T_n	SHELLEY RATING R_n	SHELLEY VALUE V	SHELLEY T.VALUE T_n
2.4 PROCESS																						
2.4.1 SCHEDULING	10	.8	8		.8	8		.9	9		.9	9		.9	9		.8	8		.7	7	
2.4.2 CAPACITY	13	.7	9.1		.7	9.1		.8	10.4		.8	10.4		.8	10.4		.7	9.1		.7	9.1	
2.4.3 COORDINATION	15	.9	13.5		.9	13.5		.9	13.5		.9	13.5		.9	13.5		.9	13.5		.9	13.5	
2.4.4 PROCUREMENT	8	.8	6.4		.7	5.6		.8	6.4		.9	7.2		.7	5.6		.7	5.6		.8	6.4	
2.4.5 SUPPORT	10	.8	8		.8	8		.8	8		.8	8		.8	8		.8	8		.8	8	
2.4.6 INVENTORY	8	.7	5.6		.7	5.6		.7	5.6		.9	7.2		.7	5.6		.7	5.6		.7	5.6	
2.4.7 LEAD-TIME	6	.8	4.8		.7	4.2		.8	4.8		.8	4.8		.7	4.2		.7	4.2		.8	4.8	
2.4.8 LEARNING	4	.8	3.2		.7	2.8		.8	3.2		.9	3.6		.7	2.8		.7	2.8		.7	2.8	
2.4.9 ROUTINE	9	.8	7.2		.8	7.2		.8	7.2		.8	7.2		.8	7.2		.8	7.2		.8	7.2	
2.4.10 RETOOLING	10	.8	8		.7	7		.8	8		.8	8		.7	7		.7	7		.6	6	
2.4.11 CHARGE	7	.7	4.9		.7	4.9		.7	4.9		.8	5.6		.7	4.9		.7	4.9		.6	4.2	
TOTAL	100			78.7			75.9			81.0			84.5			78.2			75.9			74.6

Level 3. Evaluation Matrix - Mobility

HOUSING SYSTEMS / CRITERIA	CRITERIA WEIGHT C_n	B.S.I. RATING R_n	B.S.I. VALUE V	B.S.I. T.VALUE T_n	CAMCI RATING R_n	CAMCI VALUE V	CAMCI T.VALUE T_n	COMPO-NOFORM RATING R_n	COMPO-NOFORM VALUE V	COMPO-NOFORM T.VALUE T_n	DESCON CONCORDIA RATING R_n	DESCON CONCORDIA VALUE V	DESCON CONCORDIA T.VALUE T_n	FCE DILLON RATING R_n	FCE DILLON VALUE V	FCE DILLON T.VALUE T_n	ROUSE WATES RATING R_n	ROUSE WATES VALUE V	ROUSE WATES T.VALUE T_n	SHELLEY RATING R_n	SHELLEY VALUE V	SHELLEY T.VALUE T_n
3.1 MOBILITY																						
3.1.1 MOVEMENT	10	.8	8		.8	8		.9	9		.9	9		.8	8		.8	8		.5	5	
3.1.2 LOCALITY	10	.8	8		.8	8		.8	8		.9	9		.8	8		.8	8		.5	5	
3.1.3 SINGLE MODE	14	.8	11.2		.8	11.2		.8	11.2		.8	11.2		.8	11.2		.8	11.2		.8	11.2	
3.1.4 SCATTERED	12	.8	9.6		.7	8.4		.8	9.6		.8	9.6		.7	8.4		.7	8.4		.7	8.4	
3.1.5 DAMAGE	12	.8	9.6		.8	9.6		.8	9.6		.8	9.6		.7	8.4		.8	9.6		.4	4.8	
3.1.6 VANDALISM	6	.8	4.8		.8	4.8		.8	4.8		.8	4.8		.7	4.2		.8	4.8		.5	3.0	
3.1.7 CONSTRAINT	14	.8	11.2		.8	11.2		.8	11.2		.8	11.2		.8	11.2		.8	11.2		.6	8.4	
3.1.8 PACKAGING	7	.7	4.9		.8	5.6		.7	4.9		.7	4.9		.7	4.9		.7	4.9		.9	6.3	
3.1.9 WEIGHT	10	.8	8		.8	8		.8	8		.8	8		.7	7		.8	8		.6	3	
3.1.10 STAGING	5	.8	4		.8	4		.8	4		.8	4		.8	4		.8	4		.6	3	
TOTAL	100			79.3			78.8			80.3			81.3			75.3			78.1			61.1

Level 3. Evaluation Matrix – Transport Economics

CRITERIA (3.2 TRANSPORT ECONOMICS)	CRITERIA WEIGHT C_n	B.S.I. RATING R_n	B.S.I. VALUE V	B.S.I. T.VALUE T_n	CAMCI RATING R_n	CAMCI VALUE V	CAMCI T.VALUE T_n	COMPO-NOFORM RATING R_n	COMPO-NOFORM VALUE V	COMPO-NOFORM T.VALUE T_n	DESCON CONCORDIA RATING R_n	DESCON CONCORDIA VALUE V	DESCON CONCORDIA T.VALUE T_n	FCE DILLON RATING R_n	FCE DILLON VALUE V	FCE DILLON T.VALUE T_n	ROUSE WATES RATING R_n	ROUSE WATES VALUE V	ROUSE WATES T.VALUE T_n	SHELLEY RATING R_n	SHELLEY VALUE V	SHELLEY T.VALUE T_n
3.2.1 COST	20	.8	16		.8	16		.8	16		.8	16		.8	16		.8	16		.6	12	
3.2.2 AREA	15	.8	12		.8	12		.7	10.5		.8	12		.7	10.5		.8	12		.5	7.5	
3.2.3 RANGE	10	.7	7		.8	8		.8	8		.8	8		.8	8		.8	8		.6	6	
3.2.4 VARIATION	6	.7	4.2		.7	4.2		.7	4.2		.7	4.2		.7	4.2		.7	4.2		.5	3	
3.2.5 SCHDULING	12	.8	9.6		.8	9.6		.8	9.6		.8	9.6		.8	9.6		.8	9.6		.5	6	
3.2.6 TIME	8	.8	6.4		.8	6.4		.8	6.4		.9	7.2		.8	6.4		.8	6.4		.6	4.8	
3.2.7 RIGIDITY	12	.8	9.6		.8	9.6		.7	8.4		.8	9.6		.7	8.4		.8	9.6		.5	6	
3.2.8 FLOW	7	.8	5.6		.8	5.6		.8	5.6		.8	5.6		.8	5.6		.8	5.6		.7	4.9	
3.2.9 CAPITAL	10	.9	9		.9	9		.8	8		.9	9		.8	8		.9	9		.6	6	
TOTAL	100			79.4			86.4			76.7			81.2			76.7			84.4			56.2

Level 3. Evaluation Matrix - Erection procedure

HOUSING SYSTEMS / CRITERIA	CRITERIA WEIGHT C_n	B.S.I. RATING R_n	B.S.I. VALUE V	B.S.I. T.VALUE T_n	CAMCI RATING R_n	CAMCI VALUE V	CAMCI T.VALUE T_n	COMPO-NOFORM RATING R_n	COMPO-NOFORM VALUE V	COMPO-NOFORM T.VALUE T_n	DESCON CONCORDIA RATING R_n	DESCON CONCORDIA VALUE V	DESCON CONCORDIA T.VALUE T_n	FCE DILLON RATING R_n	FCE DILLON VALUE V	FCE DILLON T.VALUE T_n	ROUSE WATES RATING R_n	ROUSE WATES VALUE V	ROUSE WATES T.VALUE T_n	SHELLEY RATING R_n	SHELLEY VALUE V	SHELLEY T.VALUE T_n
3.3 ERECTION PROCEDURE																						
3.3.1 SCATTERED SITES	9	.8	7.2		.7	6.3		.7	6.3		.8	7.2		.7	6.3		.7	6.3		.5	4.5	
3.3.2 UTILITY	13	.8	10.4		.8	10.4		.8	10.4		.8	10.4		.8	10.4		.8	10.4		.4	5.2	
3.3.3 VARIETY	15	.7	10.5		.7	10.5		.7	10.5		.8	12		.7	10.5		.7	10.5		.3	4.5	
3.3.4 PREPARATION	10	.8	8		.8	8		.8	8		.8	8		.7	7		.8	8		.6	6	
3.3.5 TOPOGRAPHY	6	.9	5.4		.9	5.4		.9	5.4		.9	5.4		.7	4.2		.9	5.4		.8	4.8	
3.3.6 EMPLACEMENT	12	.8	9.6		.7	8.4		.8	9.6		.8	9.6		.7	8.4		.7	8.4		.7	8.4	
3.3.7 INVESTMENT	10	.8	8		.8	8		.8	8		.8	8		.8	8		.8	8		.8	8	
3.3.8 ACTIVITY	7	.8	5.6		.8	5.6		.8	5.6		.8	5.6		.8	5.6		.8	5.6		.8	5.6	
3.3.9 MANEUVERABILITY	8	.9	7.2		.9	7.2		.9	7.2		.9	7.2		.9	7.2		.9	7.2		.9	7.2	
3.3.10 CONNECTION	10	.8	8		.8	8		.8	8		.8	8		.8	8		.8	8		.8	8	
TOTAL	100			79.9			77.8			79			81.4			75.6			77.8			53.2

Level 3. Evaluation Matrix - Applicability

HOUSING SYSTEMS / CRITERIA	CRITERIA WEIGHT C_n	B.S.I. RATING R_n	B.S.I. VALUE V	B.S.I. T.VALUE T_n	CAMCI RATING R_n	CAMCI VALUE V	CAMCI T.VALUE T_n	COMPO-NOFORM RATING R_n	COMPO-NOFORM VALUE V	COMPO-NOFORM T.VALUE T_n	DESCON-CONCORDIA RATING R_n	DESCON-CONCORDIA VALUE V	DESCON-CONCORDIA T.VALUE T_n	FCB DILLON RATING R_n	FCB DILLON VALUE V	FCB DILLON T.VALUE T_n	ROUSE WATES RATING R_n	ROUSE WATES VALUE V	ROUSE WATES T.VALUE T_n	SHELLEY RATING R_n	SHELLEY VALUE V	SHELLEY T.VALUE T_n
4.1 APPLICABILITY																						
4.1.1 HOUSING	25	.9	22.5		.9	22.5		1	25		1	25		.9	22.5		.9	22.5		.9	22.5	
4.1.2 SUB-MARKET	20	.1	2		.1	2		1	20		.5	10		.5	10		.7	14		.7	14	
4.1.3 TYPE	10	.4	4		.5	5		.9	9		.6	6		.6	6		.7	7		.6	6	
4.1.4 SECTORS	15	.9	13.5		.9	13.5		.9	13.5		.9	13.5		.9	13.5		.9	13.5		.9	13.5	
4.1.5 RENEWAL	25	.8	20		.1	2.5		.8	20		.8	20		.8	20		.8	20		.1	2.5	
4.1.6 REHABILITATION	5	.0	0		0	0		0	0		0	0		0	0		0	0		0	0	
TOTAL	100			62			45.5			87.5			74.5			72			77			58.5

level 3. Evaluation Matrix – Distribution

HOUSING SYSTEMS / CRITERIA	CRITERIA WEIGHT C_n	B.S.I. RATING R_n	B.S.I. VALUE V	B.S.I. T.VALUE T_n	CAMCI RATING R_n	CAMCI VALUE V	CAMCI T.VALUE T_n	COMPO-NOFORM RATING R_n	COMPO-NOFORM VALUE V	COMPO-NOFORM T.VALUE T_n	DESCON CONCORDIA RATING R_n	DESCON CONCORDIA VALUE V	DESCON CONCORDIA T.VALUE T_n	PCE DILLON RATING R_n	PCE DILLON VALUE V	PCE DILLON T.VALUE T_n	ROUSE WATES RATING R_n	ROUSE WATES VALUE V	ROUSE WATES T.VALUE T_n	SHELLEY RATING R_n	SHELLEY VALUE V	SHELLEY T.VALUE T_n
4.2 DISTRIBUTION																						
4.2.1 PLAN	25	.7	17.5		.7	17.5		.7	17.5		.8	20		.7	17.5		.6	15		.6	15	
4.2.2 ABSORPTION	20	.7	14		.7	14		.8	16		1	20		.8	16		.7	14		.3	6	
4.2.3 LICENCE	10	.7	7		.6	6		.6	6		.9	9		.7	7		.6	6		.6	6	
4.2.4 BUILDER	10	.8	8		.8	8		.8	8		.7	7		.9	9		.8	8		.7	7	
4.2.5 FRANCHISE	10	.8	8		.8	8		.8	8		.8	8		.8	8		.8	8		.8	8	
4.2.6 VOLUME	15	.7	10.5		.6	9		.7	10.5		.7	10.5		.9	13.5		.6	9		.6	9	
4.2.7 RADIUS	10	.7	7		.7	7		.8	8		1	10		.9	9		.7	7		.4	4	
TOTAL	100			72			69.5			74			84.5			80			67			55

Level 3. Evaluation Matrix - Acceptability

CRITERIA	C_n WEIGHT	B.S.I. R_n	B.S.I. V	B.S.I. T_n	CAMCI R_n	CAMCI V	CAMCI T_n	COMPC-NOFORM R_n	COMPC-NOFORM V	COMPC-NOFORM T_n	DESCON CONCORDIA R_n	DESCON CONCORDIA V	DESCON CONCORDIA T_n	FCE DILLON R_n	FCE DILLON V	FCE DILLON T_n	ROUSE WATES R_n	ROUSE WATES V	ROUSE WATES T_n	SHELLEY R_n	SHELLEY V	SHELLEY T_n
4.3 ACCEPTABILITY																						
4.3.1 PREFERENCE	12	.8	9.6		.8	9.6		.8	9.6		.9	10.8		.8	9.6		.8	9.6		.6	7.2	
4.3.2 EXPECTATION	10	.8	8		.9	9		.8	8		.8	8		.8	8		.8	8		.6	6	
4.3.3 COMFORT	8	.8	6.4		.8	6.4		.8	6.4		.8	6.4		.8	6.4		.8	6.4		.8	6.4	
4.3.4 IMAGE	6	.7	4.2		.8	4.8		.8	4.8		.8	4.8		.8	4.8		.7	4.2		.6	3.6	
4.3.5 PROFESSION	10	.8	8		.8	8		.9	9		.9	9		.8	8		.8	8		.8	8	
4.3.6 UNIONS	10	.8	8		.8	8		.8	8		.8	8		.8	8		.8	8		.7	7	
4.3.7 LENDERS	12	.9	10.8		.9	10.8		.9	10.8		.9	10.8		.9	10.8		.9	10.8		.8	9.6	
4.3.8 MODEL CODES	10	1	10		1	10		1	10		1	10		1	10		1	10		1	10	
4.3.9 INDUSTRY CODES	10	1	10		1	10		1	10		1	10		1	10		1	10		1	10	
4.3.10 COMPETITIVE	12	.8	9.6		.7	8.4		.9	10.8		.9	10.8		.8	9.6		.7	8.4		.6	7.2	
TOTAL	100			85.6			84			87.4			88.6			85.2			83.4			75

Level 3. Evaluation Matrix - Flexibility

HOUSING SYSTEMS / CRITERIA	CRITERIA WEIGHT C_n	B.S.I.			CAMCI			COMPO-NOFORM			DESCON CONCORDIA			FCE DILLON			ROUSE WATES			SHELLEY		
4.4 FLEXIBILITY		RATING R_n	VALUE V	T.VALUE T_n	RATING R_n	VALUE V	T.VALUE T_n	RATING R_n	VALUE V	T.VALUE T_n	RATING R_n	VALUE V	T.VALUE T_n	RATING R_n	VALUE V	T.VALUE T_n	RATING R_n	VALUE V	T.VALUE T_n	RATING R_n	VALUE V	T.VALUE T_n
4.4.1 RESPONSE	25	.9	22.5		.8	20		1	25		1	25		.8	20		.8	20		.7	17.5	
4.4.2 SPECTRUM	20	.9	18		.9	18		.9	18		.9	18		.9	18		.9	18		.7	14	
4.4.3 COSTS	20	.7	14		.6	12		.8	16		.8	16		.8	16		.8	16		.8	16	
4.4.4 OVERHEAD	15	.8	12		.5	7.5		.7	10.5		.8	12		.7	10.5		.6	9		.4	6	
4.4.5 CONCURRENT	20	.9	18		.7	14		.8	16		.9	18		.7	14		.8	16		.5	10	
TOTAL	100			84.5			71.5			85.5			89			78.5			79			63.5

Level 3. Evaluation Matrix – Investment

HOUSING SYSTEMS / CRITERIA	CRITERIA WEIGHT C_n	B.S.I. RATING R_n	B.S.I. VALUE V	B.S.I. T.VALUE T_n	CAMCI RATING R_n	CAMCI VALUE V	CAMCI T.VALUE T_n	COMPO-NOFORM RATING R_n	COMPO-NOFORM VALUE V	COMPO-NOFORM T.VALUE T_n	DESCON-CONCORDIA RATING R_n	DESCON-CONCORDIA VALUE V	DESCON-CONCORDIA T.VALUE T_n	FCE DILLON RATING R_n	FCE DILLON VALUE V	FCE DILLON T.VALUE T_n	ROUSE WATES RATING R_n	ROUSE WATES VALUE V	ROUSE WATES T.VALUE T_n	SHELLEY RATING R_n	SHELLEY VALUE V	SHELLEY T.VALUE T_n
5.1 INVESTMENT																						
5.1.1 SYSTEM	25	.8	20		.8	20		.8	20		.8	20		.8	20		.8	20		.8	20	
5.1.2 PLANT	18	.8	14.4		.8	14.4		.8	14.4		1	18		.8	14.4		.8	14.4		.7	12.4	
5.1.3 SOURCES	15	.7	10.5		.7	10.5		.7	10.5		.7	10.5		.8	12		.7	10.5		.7	10.5	
5.1.4 AMORTIZATION	10	.7	7		.6	6		.6	6		1	10		.7	7		.6	6		.3	3	
5.1.5 RETURN	12	.8	9.6		.8	9.6		.9	10.8		1	12		.9	10.8		.8	9.6		.8	9.6	
5.1.6 RECOVERY	10	.8	8		.8	8		.9	9		.9	9		.8	8		.8	8		.7	7	
5.1.7 PROFIT	10	.7	7		.7	7		.9	9		.9	9		.8	8		.7	7		.7	7	
TOTAL	100			76.5			75.5			78.7			88.5			80.2			75.5			69.7

Level 3. Evaluation Matrix – Operation

HOUSING SYSTEMS / CRITERIA	CRITERIA WEIGHT C_n	B.S.I. RATING R_n	B.S.I. VALUE V	B.S.I. T.VALUE T_n	CAMCI RATING R_n	CAMCI VALUE V	CAMCI T.VALUE T_n	COMPO-NOFORM RATING R_n	COMPO-NOFORM VALUE V	COMPO-NOFORM T.VALUE T_n	DESCON CONCORDIA RATING R_n	DESCON CONCORDIA VALUE V	DESCON CONCORDIA T.VALUE T_n	FCE DILLON RATING R_n	FCE DILLON VALUE V	FCE DILLON T.VALUE T_n	ROUSE WATES RATING R_n	ROUSE WATES VALUE V	ROUSE WATES T.VALUE T_n	SHELLEY RATING R_n	SHELLEY VALUE V	SHELLEY T.VALUE T_n
5.2 OPERATION																						
5.2.1 WORKING CAPITAL	30	.8	24		.8	24		.8	24		1	30		.8	24		.8	24		.6	18	
5.2.2 EXPENDITURES	25	.8	20		.7	17.5		.8	20		1	25		.7	17.5		.7	17.5		.7	17.5	
5.2.3 ALLIANCE	20	.8	16		.8	16		.8	16		.6	12		.9	18		.8	16		.6	12	
5.2.4 EXTENSION	15	.8	12		.8	12		.8	12		.8	12		.9	13.5		.8	12		.8	12	
5.2.5 DIVERSIFICATION	10	.6	6		.6	6		.6	6		.5	5		.8	8		.6	6		.7	7	
TOTAL	100			78			75.5			78			84			81			75.5			66.5

Level 3. Evaluation Matrix - Costs

HOUSING SYSTEMS / CRITERIA	CRITERIA WEIGHT G_n	B.S.I. RATING R_n	B.S.I. VALUE V	B.S.I. T.VALUE T_n	CAMCI RATING R_n	CAMCI VALUE V	CAMCI T.VALUE T_n	COMPO-NOFORM RATING R_n	COMPO-NOFORM VALUE V	COMPO-NOFORM T.VALUE T_n	DESCON CONCORDIA RATING R_n	DESCON CONCORDIA VALUE V	DESCON CONCORDIA T.VALUE T_n	FCE DILLON RATING R_n	FCE DILLON VALUE V	FCE DILLON T.VALUE T_n	ROUSE WATES RATING R_n	ROUSE WATES VALUE V	ROUSE WATES T.VALUE T_n	SHELLEY RATING R_n	SHELLEY VALUE V	SHELLEY T.VALUE T_n
5.3 COSTS																						
5.3.1 SAVINGS	20	.9	18		.9	18		.9	18		.9	18		.9	18		.9	18		.9	18	
5.3.2 DIFFERENTIAL	15	.9	13.5		.9	13.5		.9	13.5		.9	13.5		.9	13.5		.9	13.5		.9	13.5	
5.3.3 PRODUCTIVITY	15	.9	13.5		.9	13.5		.9	13.5		.9	13.5		.9	13.5		.9	13.5		.9	13.5	
5.3.4 ADD-ON-COSTS	13	.9	11.7		.8	10.4		.8	10.4		.9	11.7		.8	10.4		.8	10.4		.7	9.1	
5.3.5 TAX	10	.9	9		.9	9		.9	9		.9	9		.9	9		.9	9		.9	9	
5.3.6 SHORT-TERM	15	.9	13.5		.9	13.5		.9	13.5		.9	13.5		.9	13.5		.9	13.5		.9	13.5	
5.3.7 QUALITY	12	.8	9.6		.8	9.6		.8	9.6		.8	9.6		.8	9.6		.8	9.6		.8	9.6	
TOTAL	100			88.8			87.5			87.5			88.8			87.5			87.5			86.2

Level 3. Evaluation Matrix - Services

HOUSING SYSTEMS / CRITERIA	CRITERIA WEIGHT C_n	B.S.I. RATING R_n	B.S.I. VALUE V	B.S.I. T.VALUE T_n	CAMCI RATING R_n	CAMCI VALUE V	CAMCI T.VALUE T_n	COMPO-NOFORM RATING R_n	COMPO-NOFORM VALUE V	COMPO-NOFORM T.VALUE T_n	DESCON CONCORDIA RATING R_n	DESCON CONCORDIA VALUE V	DESCON CONCORDIA T.VALUE T_n	FGE DILLON RATING R_n	FGE DILLON VALUE V	FGE DILLON T.VALUE T_n	ROUSE WATES RATING R_n	ROUSE WATES VALUE V	ROUSE WATES T.VALUE T_n	SHELLEY RATING R_n	SHELLEY VALUE V	SHELLEY T.VALUE T_n
6.1 SERVICES																						
6.1.1 DESIGN	20	1	20		1	20		1	20		1	20		1	20		1	20		1	20	
6.1.2 PRODUCTION	14	1	14		1	14		1	14		1	14		1	14		1	14		1	14	
6.1.3 TRANSPORTATION	10	.8	8		.8	8		.8	8		.8	8		.9	9		.8	8		.8	8	
6.1.4 CONSTRUCTION	8	.3	2.4		.4	3.2		.4	3.2		.4	3.2		.5	4		.3	2.4		.1	.8	
6.1.5 MARKETING	18	.7	12.6		.5	9		.5	9		.5	9		.8	14.4		.7	12.6		.5	9	
6.1.6 FINANCING	15	.9	13.5		.9	13.5		.9	13.5		1	15		.9	13.5		.9	13.5		.9	13.5	
6.1.7 DEVELOPMENT	15	.6	9.5		.6	9		.6	9		.9	13.5		.7	10.5		.6	9		.6	9	
TOTAL	100			78.5			76.7			76.7			82.4			85.4			78.5			74.3

Level 3. Evaluation Matrix – Scope

HOUSING SYSTEMS / CRITERIA	CRITERIA WEIGHT C_n	B.S.I. RATING R_n	B.S.I. VALUE V	B.S.I. T.VALUE T_n	CAMCI RATING R_n	CAMCI VALUE V	CAMCI T.VALUE T_n	COMPO-NOFORM RATING R_n	COMPO-NOFORM VALUE V	COMPO-NOFORM T.VALUE T_n	DESCON CONCORDIA RATING R_n	DESCON CONCORDIA VALUE V	DESCON CONCORDIA T.VALUE T_n	FCE DILLON RATING R_n	FCE DILLON VALUE V	FCE DILLON T.VALUE T_n	ROUSE WATES RATING R_n	ROUSE WATES VALUE V	ROUSE WATES T.VALUE T_n	SHELLEY RATING R_n	SHELLEY VALUE V	SHELLEY T.VALUE T_n
6.2 SCOPE																						
6.2.1 UNITY	20	.6	12		.9	18		.5	10		.4	8		.8	16		.7	14		.9	18	
6.2.2 GENERATION	25	.7	17.5		.8	20		.7	17.5		.7	17.5		.8	20		.7	17.5		.8	20	
6.2.3 FEASIBILITY	20	.8	16		.9	18		.7	14		1	20		.8	16		.8	16		.9	18	
6.2.4 HOLDING COMPANY	10	.7	7		.9	9		.7	7		.7	7		.8	8		.7	7		.9	9	
6.2.5 FEEDBACK	15	.9	13.5		.9	13.5		.7	12.5		.9	13.5		.9	13.5		.9	13.5		.9	13.5	
6.2.6 EVALUATION	10	.8	8		.8	8		.8	8		.8	8		.8	8		.8	8		.8	8	
TOTAL	100			74			86.5			67			74			81.5			76			86.5

documented input from publications of competing industrialized housing systems (1-27, 31-41). However, the process of weighting has been carried out in an open forum with the participation of several architects, engineers, and professionals. However, only one has been involved during all the phases of the Operation BREAKTHROUGH program.

The judgment for the assignment of the criteria weight constants have been carried out at all three levels by graduate students. However, it is acknowledged that the criteria weight constants may be modified with more competent evaluation team participants, change of location (i.e., developing countries versus North America), and passage of time.

For example, for the level 1 criteria, we have arrived at the following criteria weight constants:

1.	Design	18
2.	Production	18
3.	Transportation and Erection	12
4.	Marketing	15
5.	Financing	22
6.	Organization	15
	Total	100

It should be noted that vested interests of the evaluators will change these weightings — if for instance, only an architect, or a producer, or an owner alone wants

to weight these criteria, it is quite obvious that each
will give differing emphasis to the weightings. As for
an architect, design would have the highest weight; for
a producer, production and marketing would have the
highest weight; and for an owner, financing might be the
highest preference. Therefore, the validity and importance
of this evaluation procedure depends on the formation
of the evaluation team so as to consist of only pro-
fessionals representing the total spectrum of necessary
disciplinary inputs.

In all cases, a sensitivity analysis should be
carried out to determine if minor changes in bias of the
evaluators might change measurably the final results.

An example of this might be a consensus agree-
ment to re-run the evaluation analysis, changing the
weighting for Transportation and Erection from 12 to 14,
and Financing from 22 to 20. The results might cause a
major shift from a system with low ratings in Transpor-
tation and Erection and high ratings in Financing to a
system with the reverse ratings. This analysis should
always be done as the effect of weighting is usually
dominant over individual ratings.

The judgment of ratings which are to be entered
at level 3 only, are the quantitative assignments of
values within the mutually related groups of criteria
to indicate how effectively a specific housing system

can potentially satisfy these criteria. These ratings
are assigned on a scale of $0.00 \leq R_n \leq 1.00$.
A criterion assigned a rating value of $R = 1.00$ is
judged to have a very high probability of being
effectively satisfied by the housing system under
evaluation, whereas, the requirements of a criteria
with a rating value of $R = 0.50$ or less are not
likely to be effectively met by the system in
question. Because these values are ratings and not
rankings, several criteria may be assigned rating
value of $R = 1.00$ within a mutually related group
of criteria for a particularly applicable system.
Conversely, a poor or inappropriate system may
not fully satisfy any criteria within a mutually
related group, so that very low rating values
will be assigned. These ratings, unlike the criteria
weight assignments which are constant for all
systems, are variable and will differ in the
evaluation of alternative systems.

It should be noted that the evaluation
process permits subjective and objective application of
both weighting and rating.

Because of the inexperience of the
student evaluation team and each of accessable

objective data, many ratings became subjective
when objective ratings were potentially possible.
This of course has reduced the validity of the
conclusions.

The following are three example, selected
randomly from the matrices, to explain how the
ratings were assigned:

Example 1. On page 121, for the criterion
3.2 Transportation Economics; criteria 3.2.4,
3.2.5, and 3.2.6 are rated subjectively only because
objective data were not available while criteria
3.2.1, 3.2.2, 3.2.3, 3.2.7, 3.2.8, and 3.2.9 are rated
objectively because of availability of the required
data (25-27, 31-41).

Example 2. On page 124, for the criterion
4.2 Distribution; criteria 4.2.1, 4.2.2, and 4.2.6 are
rated subjectively (i.e., an assessment of statistics
and projections) while criteria 4.2.3, 4.2.4, 4.2.5 and
4.2.7 are rated objectively because of availability of
the required data (25-27, 31-41).

Example 3. On page 129, for the criterion
5.3 Costs; all the criteria, 5.3.1 through 5.3.7 are
rated objectively because of availability of the
required data (25-27, 31-41).

Based on our analysis and evaluation, the relative overall performance effectiveness indexes for the seven proposed high density industrialized housing systems suggest the following order of selection:

Rank	Industrialized Housing Systems	Overall Performance Effectiveness Index
1	Descon/Concordia System	84.00
2	Componoform System	80.80
3	FCE-Dillon System	80.00
4	Building System International	79.40
5	Rouse-Wates System	78.20
6	Camci System	77.30
7	Shelley System	71.20

Figure 60, is the comparative graphical illustration of Level 1 performance criteria versus their relative performance effectiveness indexes (total values) calculated at Level 2 for the seven proposed high density industrialized housing systems. It shows the hierarchy of the systems at Level 1 performance criteria, i.e., design, production, transportation and erection, marketing, financing, and organization.
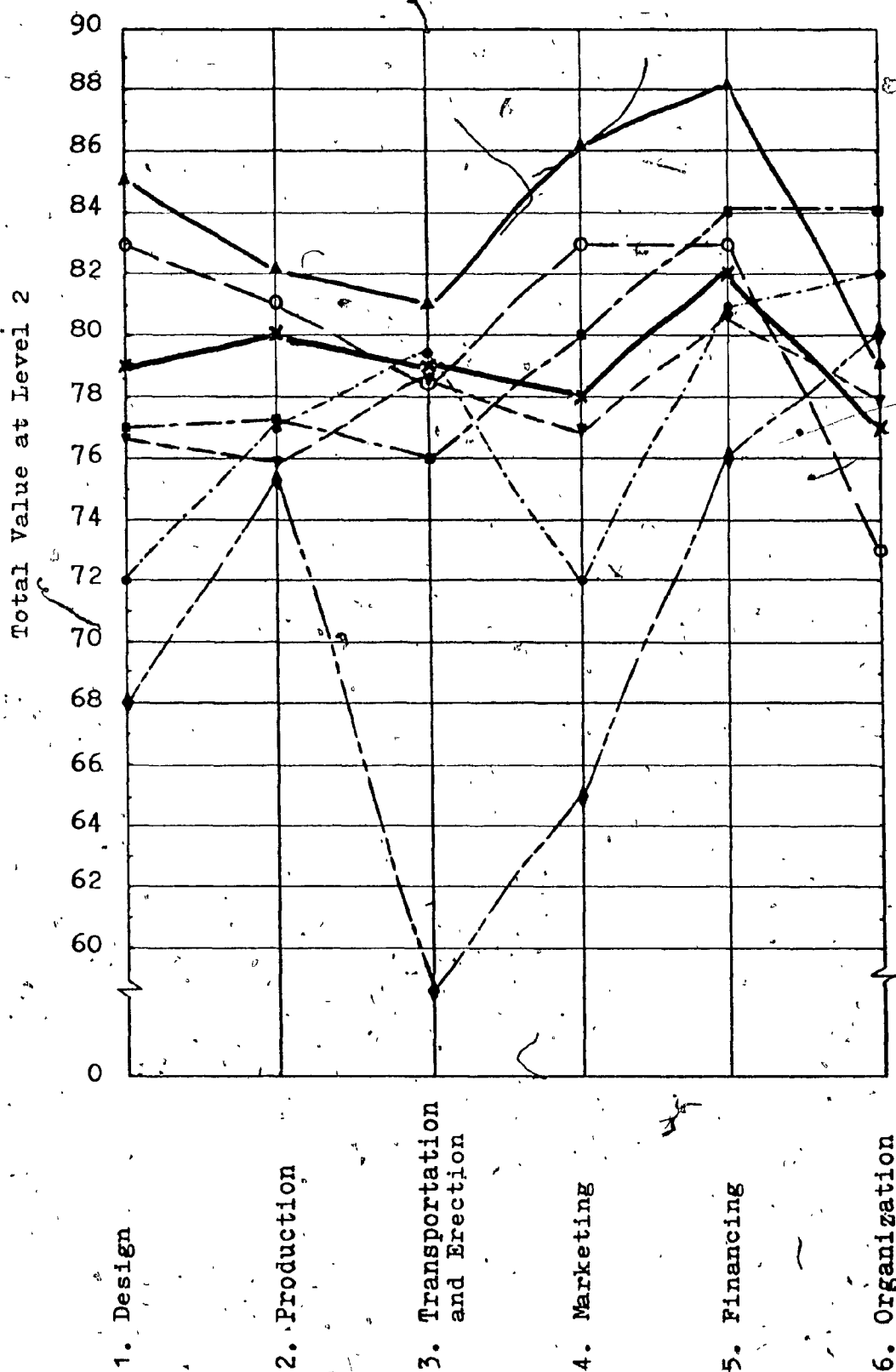
Level 1 Performance Criteria

(Legend on next page)

Legend

X ────────── Building System International

● ─·─·─·─·─ Camci System

O ── ── ── ── Componoform System

▲ ────────── Descon/concordia System

■ ─··─··─··─ FCE-Dillon System

▼ ── ── ── ── Rouse-Wates System

◆ ── ── ── ── Shelley System

Figure 60. Comparative Profiles of Performance Effective-
ness Indexes (Total Value) at Level 2, Versus
Performance Criteria at Level 1, for The Seven
Proposed High Density Industrialized Housing
Systems.

Descon/Concordia System   (now Descon System Ltd.)
has the highest performance effectiveness index relative
to the other systems. However, for the organization
criteria, its performance effectiveness index (total
value at Level 2) is ranked fourth relative to the other
systems. This was due to the U.S. government decision
to unilaterally terminate their contract for "default"
during the Operation BREAKTHROUGH program in 1973.
This decision was reversed in 1977, and the contract
terminated for "convenience", but only after involving
Descon Management staff for 5 years in legal battle
before the United States Housing and Urban Development
Board of Contract Appeals. They would have otherwise
had a chance to expand their organization and could have
been rated even higher. It is understood that with the
recovery of all their costs from the Operation BREAK-
THROUGH program, the company will reorganize for mass
production in North America and overseas.

Shelley System has the lowest overall performance
effectiveness index relative to the other systems. For
its transportation and erection criteria, it has the
lowest performance effectiveness index, because of its
design constraints and limitations which has also
resulted in the lowest performance effectiveness index
for its marketing criteria relative to the other systems.

CONCLUSION

Greater industrialzation of the construction industry, especially that of housing, offers the best solution to the ever growing problem, of the housing crisis throughout the world. The conventional housing construction can not meet the required need for shelters for the growing population of the world. Housing in the developed country has sky-rocketted in cost, especially due to higher rate of labor and low productivity.

By industrialization of housing construction and mass productions, the construction period can be shortened, the cost can be lowered, the quality can be improved thus enabling responsible housing authorities to overcome the problems of the housing shortage.

There are basically two types of industrialized building systems. One is "Closed Systems", such as box-modules which are highly industrialized and the other is "Open Systems" which are architecturally more flexible.

Seven high density industrialized housing systems have been studied and evaluated based on their relative performance effectiveness with respect to their capabilities to satisfy a series of technological and economical performance criteria.

The evaluation was carried out through evaluation

matrices. It is very important to recognize that the con-
clusions reached have potential limitations due to lack of
present activity of most of the systems in North America
at this time. Many, due to lack of aggregated markets are
not viable and able to compete with traditional housing
construction. For instance, a housing system could achieve
a very high overall effectiveness index yet have many un-
favourable characteristics which in the computation could
outweighted by its positive features. If these characteris-
tics related, for example, to a need for a high guaranteed
annual production and the housing system was selected and
constructed on the basis of high overall performance effec-
tiveness index, a catastrophic economical failure might
result. Therefore, an important assumption and pre-requisite
of the procedure proposed is that only industrialized
housing systems able to satisfy all existing standards of
acceptability, whether they be regulatory, economic, or
consumer related, should be considered for evaluation.
In making the required initial judgment, if a system is
deemed unable to satisfy known standards, it should be
rejected from further consideration. No system, regardless
of innovative design, efficient production, or ingenious
management techniques, is of any practical value unless
it can fully compete in the market place in every respect
with accepted conventional methods of construction.

BIBLIOGRAPHY

1. Auerbach, H., Dawson, W.F.; "Feedback from Operation
   Breakthrough: Procedures and Objectives",
   Industrialized Forum, Vol. 6, No. 1, 1975.

2. Bender, Richard; "A Crack in The Rear-View Mirror",
   Van Nostrand Reinhold, N.Y. and Toronto, 1973.

3. Bender, R. and Parman, J.; "The Industrialization of
   the Building Site, An Analysis of Experience
   in Operation Breakthrough", IF, V. 6, No. 1,
   1975.

4. Blachere, Gerard; "Evaluation of Building Quality",
   IF, V. 1, No. 4, 1970.

5. Camous, Roger; "The Performance Concept and The Evalua-
   tion of New Building Products", IF, V. 3,
   No. 3, February 1972.

6. Charlton, Elinor; "Survey of Operation Breakthrough
   Participants", IF, V. 6, No. 1, 1975.

7. Churchman, C. West; "The System Approach", Dell Pub-
   lishing Company, N.Y., 1968.

8. Crise D.J.; "A Procedure for Assessing Expected Perfor-
   mance Effectiveness of Industrialized Housing
   Systems", JAR 4/3, December 1975.

9. Cutler, L.S. and Cutler, S.S.; "Handbook of Housing
   Systems For Designers and Developers", Van
   Nostrand Reinhold Company, N.Y., Toronto,
   1974.

10. Department of Industry, Trade and Commerce; "A System
    Approach to Building", Ottawa, 1969.

11. Dietz, Albert and Cutler, L.S.; "Industrialized Building
    Systems For Housing", M.I.T. Press, Cambridge,
    1971.

12. Harrison, H.W.; "Performance Specifications for Building
    Components", Ministry of Public Works, Watford
    England, 1969.

13. Industrialized Building Exposition and Congress Inc.;
        "Digest of Seminars", Cahners Publishing Co.,
        Chicago, 1970.

14. Margulis, Stephen, T.; "A Comparison of the Opinions of
        Operation Breakthrough Occupants and Conventional
        Housing Occupants About Their Housing", IF,
        V. 6, No. 1, 1975.

15. Pearson, K.G.; "Industrialized Housing", The University
        of Michigan, Ann Arbor, Michigan, 1972.

16. Public Works of Canada; "Project Brief System, User
        Manual", Ottawa, September 1976.

17. Reidelbach, J.A. Jr.; "Modular Housing 1971, Facts and
        Concepts", Cahners Books, Boston, 1971.

18. Roger, Richard, B.; "How to Reduce The Cost of Housing
        Through Industrialization", Proceedings of
        ISOHP-74, Concordia University, Montreal, 1974.

19. Schodeck, L. Daniel; "Operation Breakthrough: The Change
        Image", IF, V. 6, No. 1, 1975.

20. Schodeck, L. Daniel; "Evaluating The Performance of
        Buildings", IF, V. 4, No. 5, 1973.

21. Shemie, Milo; "Mechanical Joints in the Descon/Concordia
        Structural System", Proceedings Symposium on
        Panelized Structural Assemblies, Concordia
        University, Montreal, May 11-12, 1972.

22. Smith, P.S.; Herrey, Antony and Litle, A. William; "In-
        dustrialized Housing Feasibility Study", M.I.T.,
        Cambridge, Massachusetts, October 1971.

23. Stewart, John; "Operation Breakthrough and Material
        Innovation, A Producer's Viewpoint", IF, V.6,
        No. 1, 1975.

24. The Home Manufacturers' Association; "A Fact Book on Home
        Manufacturing", Washington D.C.

25. The Componoform Building System, by Componoform Inc.

26. The Descon Building System, by Descon International
        Limited, 1974.

27. The FCE-Dillon System, by FCE-Dillon Inc. 1972.

28. United Nations, Department of Economic and Social Affairs; "World Population Prospects as Assessed in 1968", Population Studies No. 53.

29. United Nations, Department of Economic and Social Affairs; "Growth of the World's Urban and Rural Population, 1920-2000", N.Y., 1969.

30. United Nations, Department of Economic and Social Affairs; "Compendium of Housing Statistics 1971", First Issue, N.Y., 1974.

31. U.S. Department of Housing and Urban Development; "Feedback Operation Breakthrough- Phase I, Design and Development of Housing Systems", Volume 1, U.S. Government Printing Office, Washington D.C., 1973.

32. U.S. Department of Housing and Urban Development; "Feedback Operation Breakthrough, A Compendium of Building Concepts", U.S. Government Printing Office, Washington D.C., Vol. 2, January 1974.

33. U.S. Department of Housing and Urban Development; "Feedback Operation Breakthrough, A Documentary of Transportation and Handling Systems", Vol. 3, U.S. Government Printing Office, Washington D.C., Aug. 1974.

34. U.S. Department of Housing and Urban Development; "Feedback Operation Breakthrough, Phase II, Prototype Construction and Demonstration", Vol. 4, U.S. Government Printing Office, Washington D.C., October 1975.

35. U.S. Department of Housing and Urban Development; "Feedback Operation Breakthrough, A Compendium of Fire-Testing", Vol. 5, U.S. Government Printing Office, Washington D.C., March 1976.

36. U.S. Department of Housing and Urban Development; "Feedback Operation Breakthrough, A Compendium of Performance Testing Programs", Vol. 6, U.S. Government Printing Office, Washington D.C., May 1976.

37. U.S. Department of Housing and Urban Development; "Feedback Operation Breakthrough, Phase II, Site Planning and Design", Vol. 7, U.S. Government Printing Office, Washington D.C., November 1976.