PDHonline Course C618 (2 PDH)

Prefabrication: An Unfulfilled Promise

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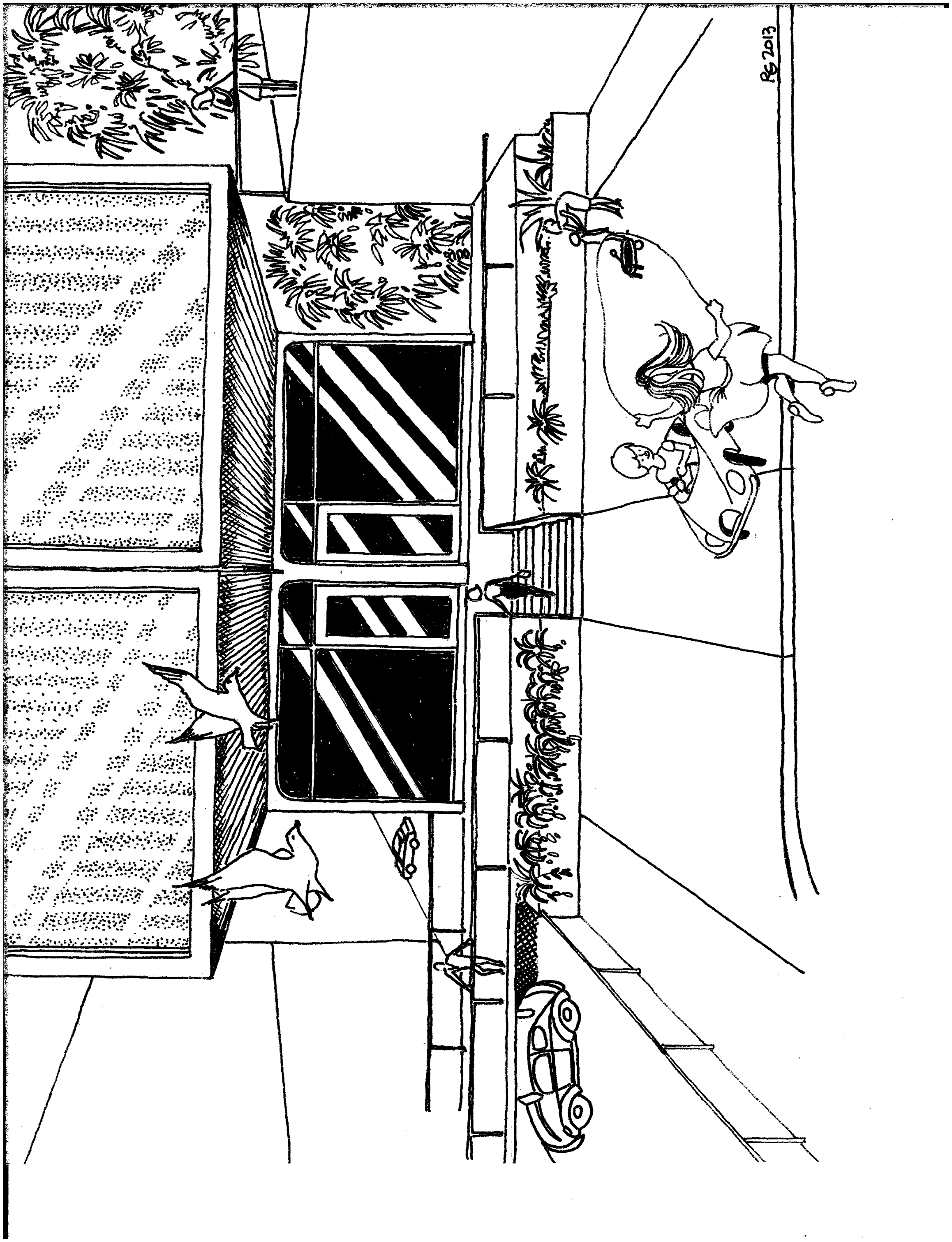
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Prefabrication: An Unfulfilled Promise

Ruben A. Gomez, P.E.

1.0 PROLOGUE

Because engineers, architects and builders are such a dispersed and un-cohesive group of people who work by the piecemeal on one job at the time basis, that is traditionally why their industry has lagged behind all others and while the consumer can go shopping on a whim and buy a boat, a car, a refrigerator, a stove or a washing machine as a prefabricated item and take it home as wished. However, when it comes to a house or a building for whatever use or purpose, it becomes an extremely complicated proposition that takes months and sometimes even years to plan and build. Painful to admit, construction is an archaic industry not much better than the "stone over stone" methodology of the past.

Attempts have been made to fill in the vacuum with the inception of the mobile home, however, the effort has not been serious and the "industry" is controlled mainly by car dealers, truck fleet owners and is regulated by the state motor vehicle departments who perceive those homes as re-locatable units. Moreover, the production of those units as assembled with substandard materials, using innumerous shortcuts and under the jurisdiction of over-permissible code regulations, has only been good to produce the so called "trailer parks" which quite frankly are nothing more but glorified slums.

As result of the population boom experienced during the twenty year period from 1945 through 1965, some government agencies felt the need to start programs to induce the industry to grow at a faster pace and thus catch up with the ever increasing popular housing demand. During the early 60's, while many of the countries in Eastern Europe mainly headed by the now disappeared Soviet Union, had already a proliferation of tenements for their low and middle class populations, the U.S. Department of Housing and Urban Development (HUD) started a competitive program open to all developers to submit their own proposals for the development and construction of mass produced low cost subsidized housing. As result of such an initiative, we saw the emergence of many good and plausible ideas towards the goal of housing mass-production. Some of those ideas will be covered in this course, not only because they were directed to solve a problem of the times, but also because they would take the construction industry along a path of standardization and a more stable source of employment for one of the most unstable segments of our workers population.

In this course we will make ample description of one of the top winning systems on HUD's Operation Breakthrough in which the author was an involved participant. Such system consisted of self-contained apartment size concrete boxes produced in a factory as finished units and trucked to the site for their erection in place. Those boxes, or *tridimensional modules* as we preferred to call them, were not only conceived to be used as components of a multifamily housing complex, but were also flexible enough to be used as classrooms in an educational set-up or even as finished rooms in a hotel facility.

2.0 WHY PREFABRICATION?

Prefabrication is not a new concept in the marketplace, the general idea has been part of all industrialized programs in the production of appliances, furniture, automotive products, boats, airplanes, agricultural equipment and a multitude of mechanical units. The advantages it presents to the manufacturing process are substantial savings in its three most important factors: *time, effort and money.*

The detractors of industrialized modular housing claim that production repetitiveness is boring and tends to lose individuality. While it is true that effective production capitalizes on repetition and standardization, it is equally true that not two finished products need to look exactly the same if that is wished. As a matter of fact, a well thought out modular system should be versatile enough to allow the architect to produce a competitive variety of facades and with a variety of small features to make every unit distinctive enough to have its own individuality and character.

On the other hand, a remarkable feature of modular prefabrication is that quality may be optimized beyond the regular standards as known in conventional construction. Quality may be factory controlled with the result of better buildings, without necessarily placing a burden of increased costs. In addition, factory produced units can be turned over all year around regardless of weather conditions. Lastly, it increases plant personnel mobility and productivity since all work is performed at ground level.

3.0 PREFABRICATION CATEGORIES

Basically speaking, prefabricated housing can be divided in two major groups:

a. Prefabrication by components
This type of production capitalizes on the maximum use of the *human scale* by limiting the maximum weight of components to 200 pounds and thus reducing the need for hoisting equipment. The most common components are: façade panels, cabinetry, grillwork, structural members and other sub-systems.

b. Modular Prefabrication
This category covers room size modules for hotel or institutional use, as well as apartment size module boxes for housing or school applications.

Since this is where the large advantages are, in this course we will concentrate on the alternative of modular prefabrication. At the same time we will not lose perception of the fact that the more complex the product is, the more expensive the factory to produce it will be. On the other hand, and even more important, the more residual work is left for the construction site, the less will be the advantages of modular prefabrication, and unfortunately this is the "Achilles' heel" in the prefabrication by components. Consequently, one may say that the main aim of any modular housing program shall be, to conceive and produce the simplest product which requires the least amount of field work. That is the concept we wish to emphasize here, the principles and benefits of the *full scale prefabrication.*

Then, if there still is any doubt, why is full prefabrication so important? The answer is simple and straightforward:
There are many reasons why and without hesitation we endorse prefabrication, amongst other

things, because it is efficient, it is faster and it also reduces production costs. As a matter of example, let us assume for a moment that we rather choose the option of prefabrication by components and figure out a way to reduce production costs by say some 40% as compared to traditional construction. Since the average building structure is worth about 30% of the total construction cost, then all we have achieved is saving a mere of 12% which may not even be worth the effort. Therefore, the more it gets done at the production plant, the higher are the chances of attaining more substantial savings. So, why being content with 12% savings when we could save the whole 40% generated by full prefabrication? Of course, that means we need to embark in full prefabrication by producing entirely finished and sealed apartment size tridimensional modules to achieve such purpose.

4.0 WHY CONCRETE?

In the recent past, there have been many attempts to produce industrialized housing by using materials such as wood, steel, aluminum, plastics, Styrofoam, urethane, cardboard or a combination of two or more of those materials. In the long run, they all have met negative results.

We support and justify the use of concrete for prefabricated buildings, for the same reasons we favor it for conventional construction, for concrete is the ideal material which fulfills all of the following requirements:

a. it is non-combustible,
b. sound-deadening
c. non-decay
d. termite proof
e. moldable into practically any shape
f. requires low maintenance
g. ingredients are available at almost any location on the planet
h. relatively low cost
j. superior durability
k. strong enough to stand to hurricanes and tornadoes.

Those qualities are hard to beat by any other known available material on Earth.

5.0 OPTIMUM MODULE SIZE

Although the word *module* is usually referred to by the architects as a repetitive, standardized and constant unit of linear measure, we on the other hand, are herein using it as a tridimensional unit represented by the factory produced concrete box itself. At the same time, such tridimensional module is also comprised of components measured as multiple or sub-multiple of the linear dimension of one yard (3 feet).

The optimum module size we developed in our practice was directly dependent on three basic considerations:

1. Minimum room sizes as determined by construction codes and/or architectural standards.

Local codes as well as FHA specifications determined the minimum floor areas and widths which normally can be accommodated within eleven and a half feet (11'- 6"). The fact that all bedrooms have to be provided with means for natural ventilation limits the number of bedrooms to two per box. The bathroom on the other hand can be solved by using mechanical ventilation means. Most boxes (modules) were designed to accommodate two bedrooms, one bath, stairway (if applicable) and balconies on both ends, or the combination of living room, dining room, kitchen, stairway (if needed) and a porch for box lengths between 36 and 40 feet.

2. Transportation constraints, such as road maximum widths and heights as well as weights.
A width of 12 feet was commonly accepted and a maximum height of 14 feet (trailer deck included) was needed to meet road bridge clear heights.

3. Handling limitations.
Because of lifting limitations, boxes longer than 40 ft. or heavier than 40 tons made the handling a bit cumbersome, especially when dealing with multistoried buildings.

Taking into account all above variables we concluded that the optimum module size was one with the following overall dimensions:

Width: 12'-0"
Height: 8'-9"
Length: 40'-0"

6.0 DESCRIPTION OF THE MODULE BOX

Once the dimensions were established and the steel molds were ordered, the module cross-section was "cast in stone" and had to be maintained through the life of the plant. Intentionally, the length was left adjustable to accommodate any lengths up to 40 feet. Top and bottom slabs were 4 in. thick and walls were 3 in. in thickness. Concrete density and strength were adjustable to design conditions. Regular 145 PCF concrete with a compressive strength of 4,000 PSI was the standard specification, unless the plans asked for any different. It should be said here that given some special circumstances of availability, it would be worthwhile to consider using lightweight concrete because of the substantial resulting savings in footings, as well as for the easier handling. The enclosed Figure 6.1 shows a typical cross-section of the module the way it was mass-produced in our plants in Rio Piedras, Puerto Rico and in Medley, Florida.

All concrete modules were cast in two main operations; both the shell (roof and walls) and the floor slab were cast separately. All electrical conduits and boxes, inserts for vertical and horizontal connectors, as well as block-outs and sleeves for plumbing parts were installed before casting. Immediately after pouring those two main components they were subjected to an accelerated steam curing and molds stripped the next day. After stripping both components they were assembled together by the connecting bolts shown on the figure called for above.

Once placed on the production assembly line, every module was the subject of strict quality control and progressed along moved by a gantry, making stops according to a pre-scheduled program. Once a particular module was finished, inspected, certified and labeled, it was then trucked to the construction site for erection in place.

There were remote sites in our portfolio, such as Paradise Mills in St. Croix where the modules had to be shipped by barge putting at risk the integrity of the boxes to the restless waters of the

Caribbean Sea, and then trucked them through the narrow roads across the island, such as it was the case as depicted on Figure 6.2 herein.

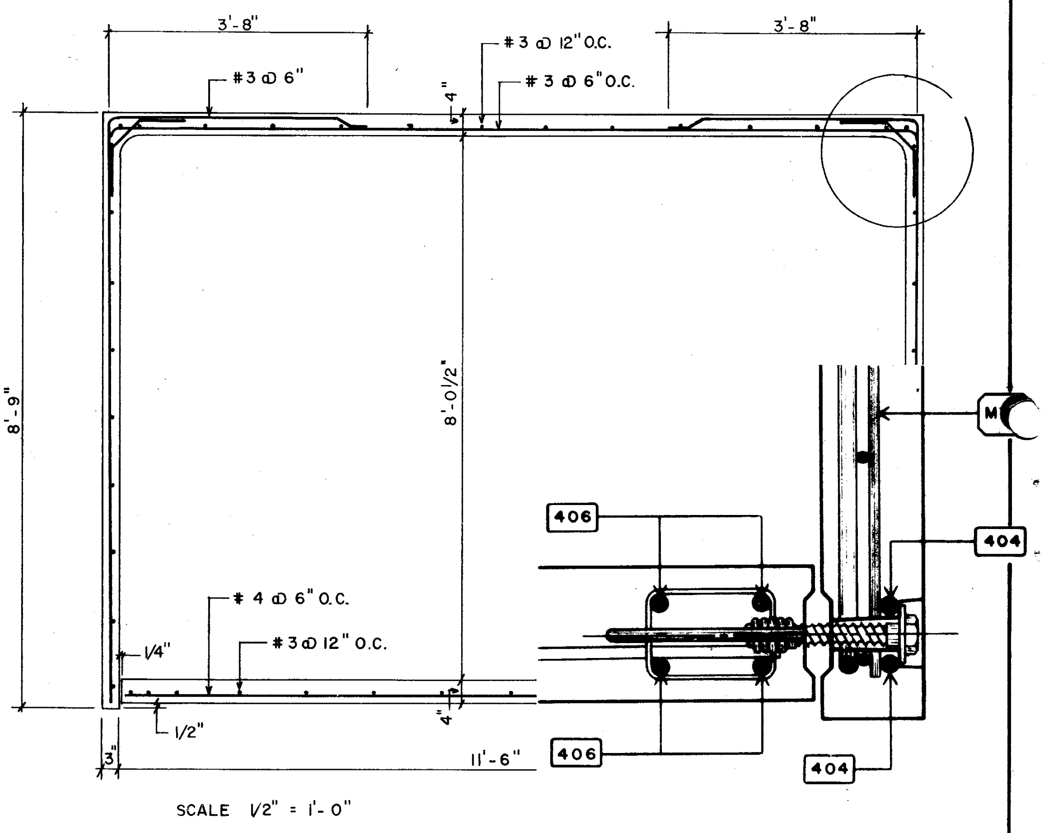
3'-8"
3'-8"
3 @ 12" O.C.
3 @ 6" O.C.
3 @ 6"
4"
8'-9"
8'-0 1/2"
M
406
404
4 @ 6" O.C.
3 @ 12" O.C.
1/4"
1/2"
4"
3"
11'-6"
406
404
SCALE 1/2" = 1'-0"

FIGURE 6.1

FIGURE 6.2

7.0 DESCRIPTION OF THE BUILDING SYSTEM

By using the already described module box, buildings of any apartment mix or configuration could be attained with the proper manipulation of the module scheme.

Structural integrity was achieved by the interaction of the following three basic characteristics:

1. Box Stiffness
All vertical loads were carried by the frame action of the concrete box, which in a great extent contributed to the resistance to lateral loads in either direction.

2. Building Geometry
Building proportion, geometry and shape were paramount in building stability and in great degree to the maximum attainable height.

3. Vertical and Horizontal Connectors
They were the key elements to provide the necessary structural continuity. In the case of walk-ups (up to five story buildings) we depended on grouted steel dowels and bolted connections.

For applications to multistoried buildings, we replaced the dowels for post-tensioning high strength steel tendons placed in vertical ducts running from the foundation up to the roof. Jacking of those tendons was done from the roof and to the designed tension forces and elongations. After jacking, the post-tensioning ducts were pressure grouted in full.

Application of vertical post-tensioning turned the cluster of individual module boxes into an integral structural system with enough ductility to withstand the design lateral loads.

From the architectural viewpoint, versatility was achieved by allowing the predetermined arrangements of one, two and or three bedroom apartments, as well as applications as single family homes, villas and townhouses.

Pleasant facades were achieved with a variety of shapes and features incorporated at relatively minimum costs. Offsets in module alignment s (both vertically and horizontally) resulted in interesting effects by creating porches, terraces and small gardens. Secondary components like planters, dividers, trellises and curtain walls also contributed to add special flavor to the architectural design.

8.0 STRUCTURAL APPROACH

The box was idealized as a rectangular frame with a hinged strap at the floor level as shown on Figure 8.1. Since none of the connecting devices and hardware utilized was stiff enough to allow for moment transmission, the entire building frame was represented as a highly redundant (yet stable) multi-hinged framework.

The so described structure was analyzed for both gravity and lateral loads with the help of an IBM 360 computer programmed with “the structural design language” ICES STRUDL II. Although some people would laugh at the way this has been herein described, and in spite of the dinosaur image projected, such piece of equipment was the “state of the art” at the time (year 1965). Analysis was performed on both, longitudinal and transverse directions.

Since boxes were stacked one on top of each other, their walls were lined up on the same vertical plane and connected to each other by separating plates and bolts (see Figure 8.2). For the purpose of analysis, in the transverse direction they were considered as a continuous shear wall from footing to roof and the lateral loads applied at each floor level. For a four story structure, the safety factor against overturning was high and calculated deflections were found to be of a negligible order.

In the longitudinal direction, as indicated before, the analysis was based on a redundant multi-hinged frame with a high degree of both, flexibility and ductility. For a hurricane Category 5 loading conditions, all bending stresses, as well as torsion stresses, were in the double digit and the deflections again were within allowable range.

For higher buildings passed the fifth floor, shear-walls were needed so as to handle lateral loads due to high winds or seismic motions.

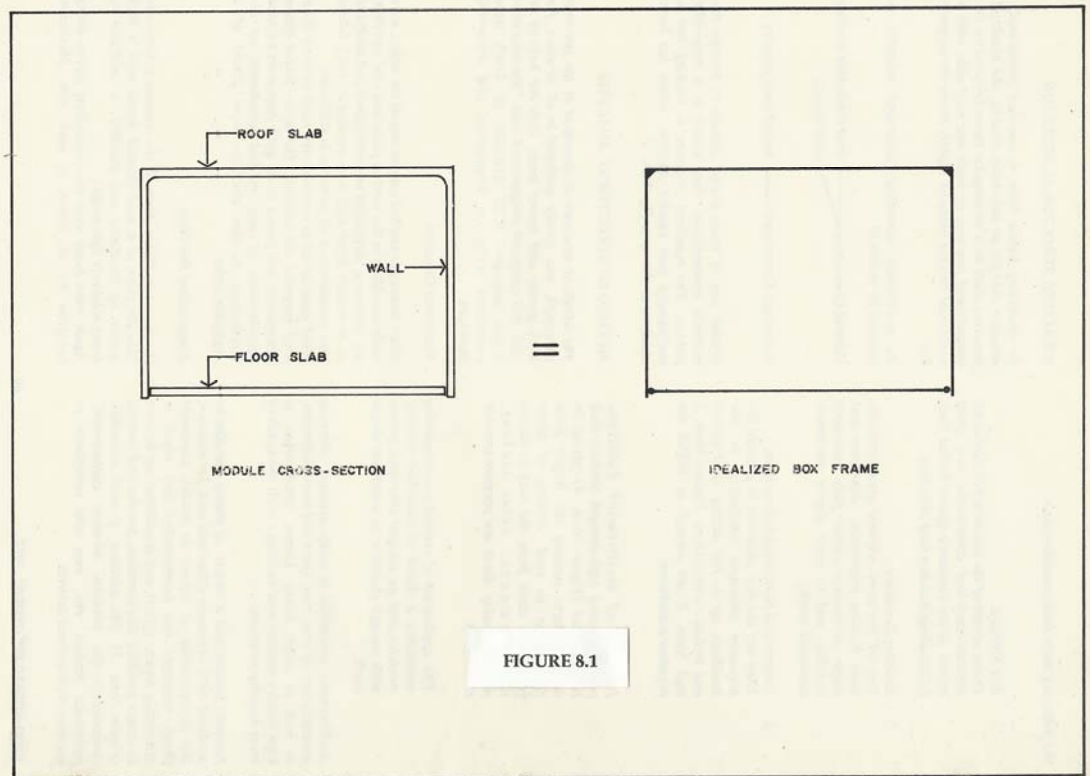
ROOF SLAB
WALL
FLOOR SLAB
=
MODULE CROSS-SECTION
IDEALIZED BOX FRAME

FIGURE 8.1

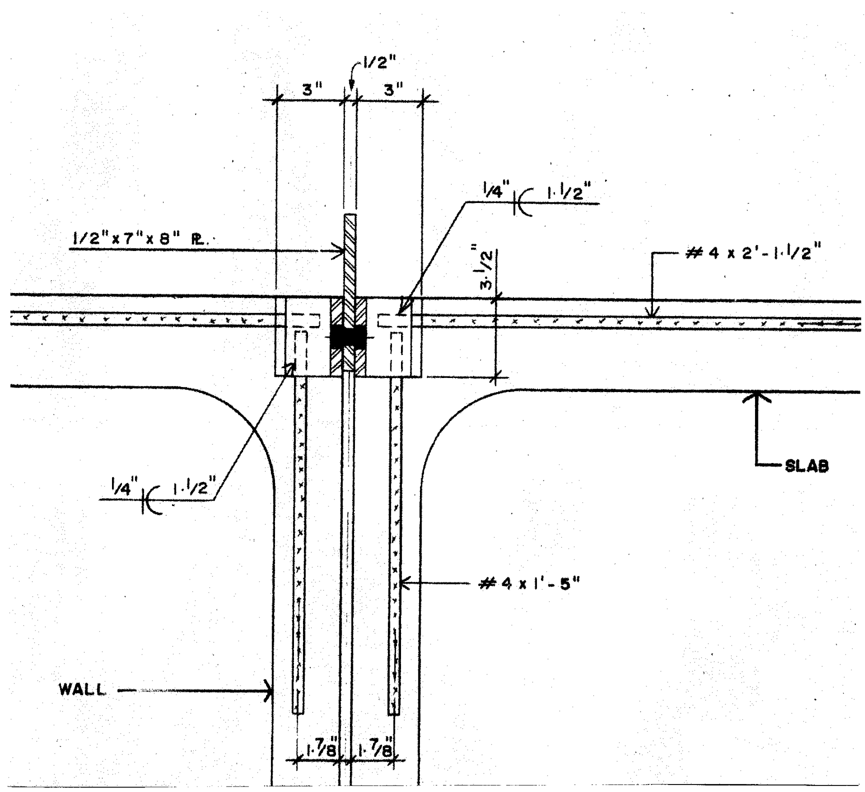

FIGURE 8.2

9.0 PLANT PRODUCTION

Figures 9.1, 9.2 and 9.3 have been enclosed in an attempt to graphically depict the general idea of a prefabrication production plant. While Figure 9.1 shows a plan view of a prefabrication plant with a single production line, Figure 9.2 provides the nomenclature for the necessary and different facilities and stages, and Figure 9.3 is a schematic view of the plant as seen from the end towards the beginning of the production line. Although the plan view is shown without a roof just for clarity, it must be said that the roof makes the plant operation almost totally independent of whatever could be going on with the weather outside, therefore, we definitively recommend a roof for tropical and semi-tropical locations for which the module was originally created. Furthermore, for cold climate locations, in addition to a roof, adequate wall enclosures are also recommended.

Once the module was cast and assembled with its floor slab bolted in place, it was run through the five stages of production and all the applicable trades, approximately in the following order:

a. grinding and patching
b. sprayed ceiling
c. roof coatings
d. partitions
e. rough plumbing and electrical
f. interior stairways (if applicable)
g. doors and windows
h. closets
j. floorings
k. kitchen and bathroom cabinets
l. plumbing fixtures
m. painting
n. electrical equipment and fixtures
p. air conditioning and heating
q. railings
r. cleaning and re-touching

As indicated above, the module box was originally conceived and designed for tropical climates, once its application is directed towards use in temperate climates; there is a need to add one more trade into the production line: rigid insulation.

The plant scheme shown herein was able to comfortably produce two modules per week. In order to increase production to one module box per day it was necessary to add one more production line and have the plant operating over-time accordingly.

A prefabrication plant is a large investment, therefore, in order to maintain efficiency and the proper return for the capital outlay, production must be kept going desirably 24 hours a day, seven days a week. In spite of all efforts made to anticipate the unforeseen, some important lessons were learned the hard way and here they are:

1. Warehouses must be well supplied with parts, materials and equipment. You cannot afford to

stop production because you ran out of reinforcing steel, electrical conduits, a toilet bowl or a particular silly bolt. The supplies must be at all times available and kept under an efficient perpetual inventory.

2. The first option should be to have your own concrete batching plant, if you are going to rely on an independent supplier make sure he is dependable and have him sign a contract with severe penalties for failure to deliver.

3. If you cannot have your own truck fleet, take the same precautions as with the concrete batching plant above.

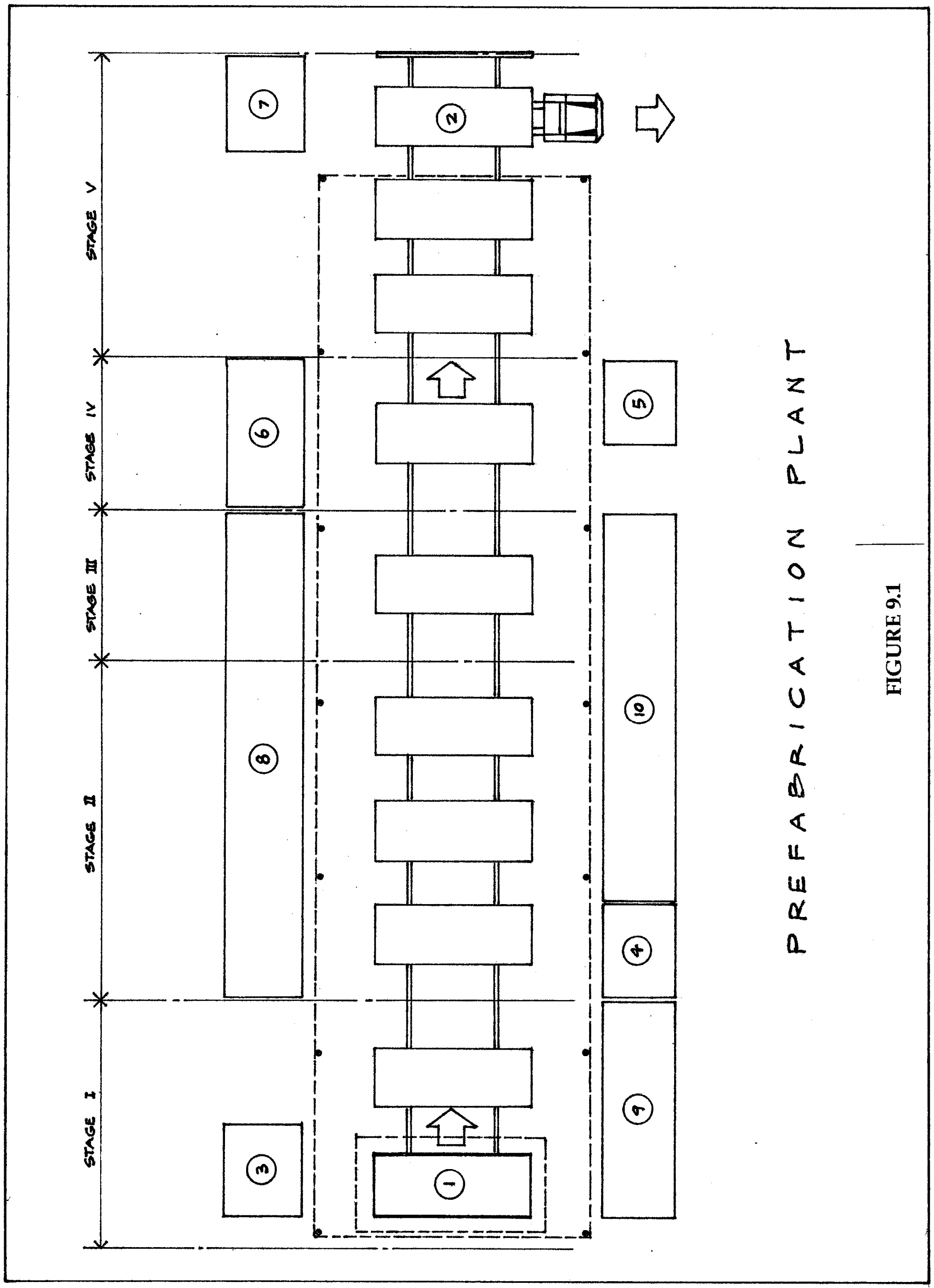

FIGURE 9.1

THE FIVE STAGES OF PRODUCTION

Stage I Casting & Curing
Stage II Partitions/Plumbing/Electrical/HVAC
Stage III Finishes/Painting
Stage IV Inspections/Cleaning
Stage V Labeling/Dispatching

NOMENCLATURE
(Key to numbers shown on plan above)

1- Casting & Curing Chamber
2- Finished module on its way to the construction site
3- Plant Manager's Office
4- Production Control
5- Quality Control
6- Inspectors' Office
7- Dispatcher
8- Plumbing & Electrical Warehouse
9- Steel Fabrication Shop
10- Carpentry & Painting Warehouse

FIGURE 9.2

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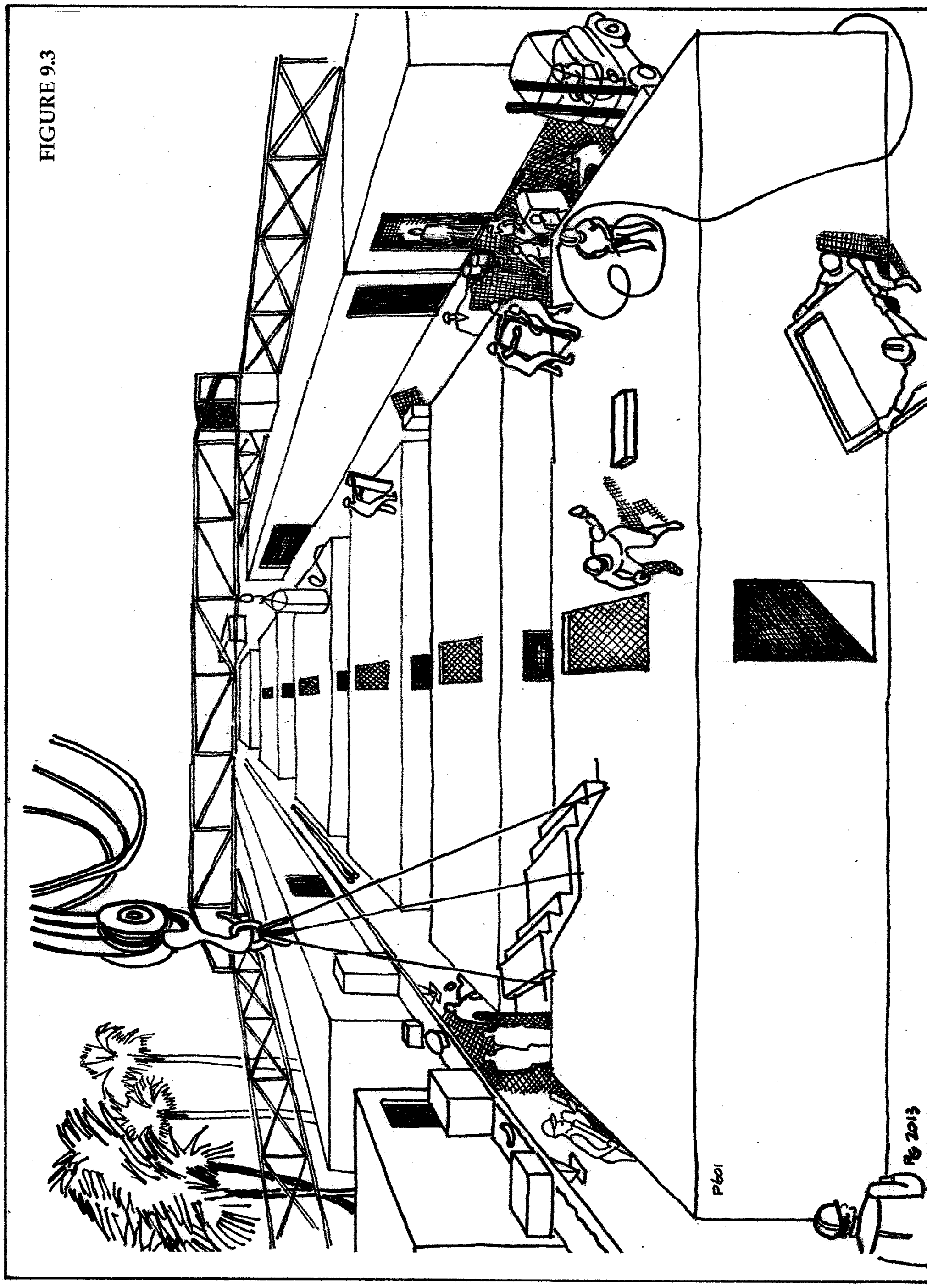

FIGURE 9.3

4. Do not make the mistake of believing that regular inspections are the same or can be used in lieu of quality control, or that they can be accomplished with the same personnel. They are not the same, nor should they be commingled as such.

5. Train your plant personnel well, turn them into real professionals in their own trades, it will pay back a tenfold. Make them feel they belong and that they are permanent and secured on their jobs. Do not cheat anyone of their hard earned wages.

6. Work with a program (such as the *critical path method*) and a realistic budget. Make your best effort to match it or beat it, especially the latter.

7. Have an effective and enforceable work safety program. Accidents on the job are not only very disruptive but can also turn out to be very costly. Most accidents can be prevented with the implementation of the proper safety precautions.

As it was affirmed at the beginning of this course, one should always remember that, like in any other construction project, is all matter of: *time, effort and money* and one must save on all three accounts to become a winner.

10.0 PRACTICAL APPLICATIONS

The module box as described above was successfully used in several housing projects. Those which are considered worthwhile of mentioning here are:

1. El Dorado Apartments, Rio Piedras, Puerto Rico (see enclosed Figure 10.1)
2. North Avenue Apartments, Santurce, Puerto Rico (see Figure 10.2)
3. Paradise Mills, St. Croix, U.S. Virgin Islands (see Figure 10.3)
4. Humbug Estates, St. Croix, USVI
5. O.L. Subsidized Housing, Opa Locka, Florida (see enclosed Figure 10.4).

FIGURE 10.1

FIGURE 10.2

FIGURE 10.3

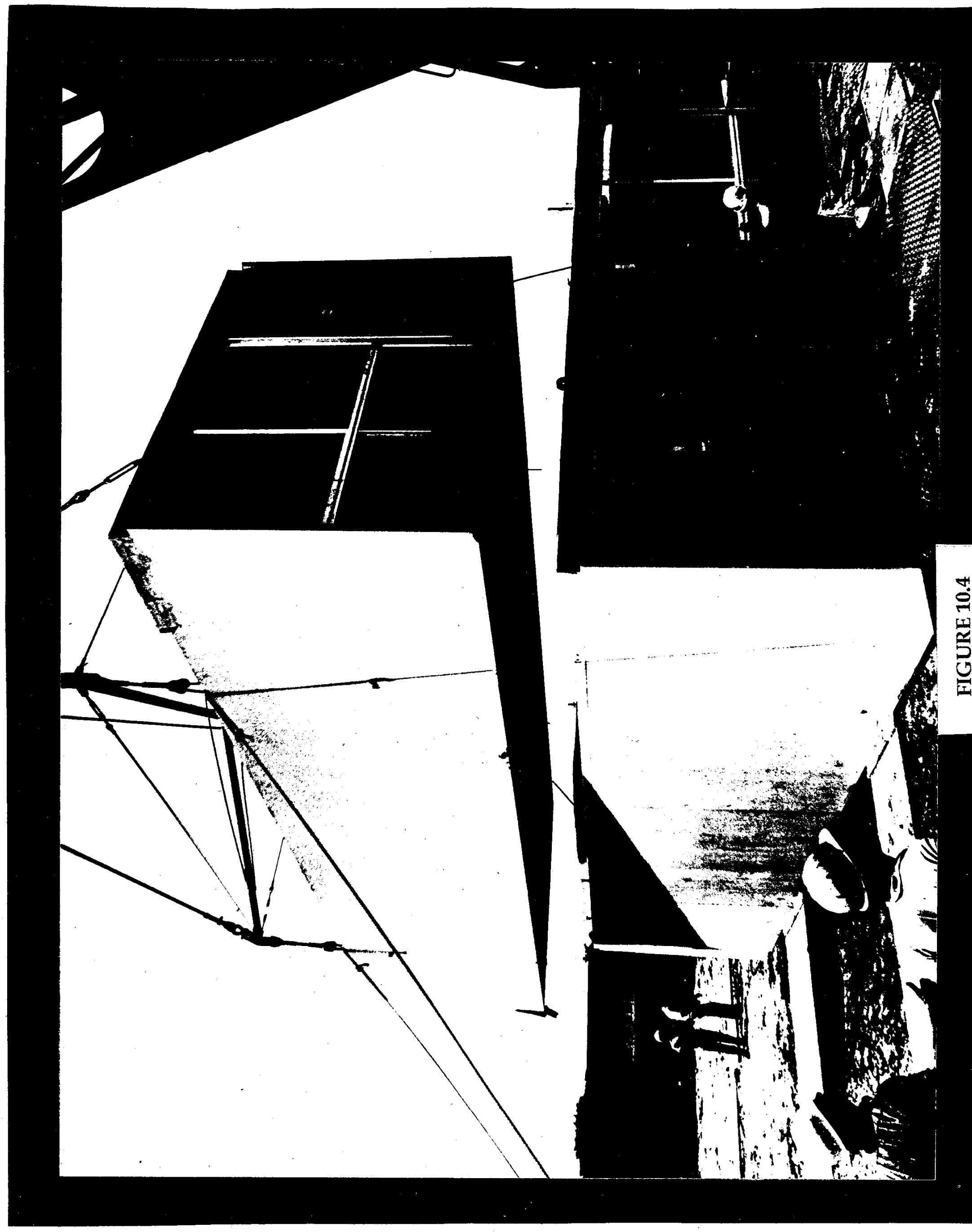

FIGURE 10.4

11.0 CONCLUSION

Although true that the U.S. economy has shrunk substantially during the period from year 2007 through 2012, and in the opinion of many, it is still shrinking as result of some of the abuses of the past. During that period of time the inventory of available housing units has increased due to abandonment, foreclosures and the resulting re-compaction of the American families all across the United States of America, thus creating a "buyer's market with a fewer buyers". However, there are some signs of recovery in the horizon and when the excess inventory gets re-absorbed, we will go back to needing new housing and at such time prefabrication will show once more its superior values as a solution to provide mass produced housing at reasonable prices for both low and medium classes, and a handsome profit for those us with the vision and preparedness, because *prefabrication is still an unfulfilled promise.*

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