

A SYSTEM OF INDUSTRIALIZED HOUSING FOR DEVELOPING COUNTRIES

A thesis submitted in partial fulfillment of the requirements for the degree of Master in Architecture at the Massachusetts Institute of Technology.

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THE ABSTRACT

The purpose of this study is the development of a system of housing, produced by United States industry, for use in developing countries. The system is of a prototype nature making maximum use of the repetition of a minimum number of parts to produce a system of greatest flexibility; single and multi-story, apartment and detached, extreme low cost and middle income, expandable, adaptable to some other building types, and having a possible United States market. The system also uses the best capacities of both the United States and the developing country as to materials, technology and labor.

Cambridge, Massachusetts

July 25, 1962

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Dear Dean Belluschi:

I hereby submit this thesis entitled, "A System of Industrialized Housing For Developing Countries", in partial fulfillment of the requirements for the degree of Master in Architecture.

Sincerely,

William Kirby Lockard

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THE PROBLEM

It is unnecessary to spend a great deal of time establishing the need for housing in developing countries. After food, shelter is considered the most basic human need. However, since it requires a larger lump investment than food or clothing, in countries which have a per capita income less than \$200, adequate shelter has had to wait.

The housing problem is compounded by many other problems in developing countries: the population explosion, the urban migration, antiquated land policies, lack of public services such as water, sewers, electricity, and fuel, and absence of any means or system of financing construction. Thus, the housing problem emerges as more an economic, social, and political problem than a technical one. And in most developing countries its proper place is third behind food and education.

In its most extreme form, the housing shortage has produced "squatters". These people erect the most primitive shelters from cast-off junk on land they do not own. In many of the major cities of the developing countries they constitute a surprising percentage of the population. "Ankara is 45% squatters; Manila - 25%; Karachi - 25%. There are an estimated 600,000 street-sleepers in Calcutta, and 700,000 in Bombay."¹ The "Ranchos" of Caracas have become an accepted, if not welcome, part of the city. The architecture of the squatters has been called the real International Style.

¹ Abrams, Chas., class notes from 4.82 Land Economics Seminar, M.I.T., 1962

If a housing program of any volume were to be undertaken in any of the developing countries, it would suffer the penalty of a very primitive building industry. Building products of the most elementary kinds are not available, and in many cases the building trades, where they exist, are extremely backward.

This is the area where the industry of the United States could be of great help. For the purpose of this study, it is assumed that someone would be willing and able to pay for this help.

In the United States housing is second only to food production as a national industry. Although housing starts for this year are expected to be over 1 million, the great postwar need for housing has been satisfied and the continued demand is more a measure of our affluent society.

With our balance of payments problem and our diminishing gold reserve, an increase in our exports over imports is much sought. Housing, or building products, seem a logical possibility.

For one thing, profits in the building products industry are down. "During this, the greatest boom in history, its (manufacture of building materials) profit margins have gone almost steadily down..... A reasonable assumption is that the mounting wages of the period, the greater complexity of carrying on under mounting numbers of rules and regulations, put a premium on production in big quantity and long runs, under simplified methods of selling and moving goods, where as it has put a penalty on the opposite. And these advantages the manufacturer in the building field simply

did not have."¹

If industrialized housing could be developed as an export, it could provide just the opportunities for profit which have been lost to the building component manufacturer: long runs and standardization, with a minimum of regulation and sales complications. This last still assumes that the whole program would be subsidized as it would have to be.

It is also reasonable to assume that developing countries would be prepared to accept the economies of industrialized housing which our own country by-passed.

Another factor is our foreign aid program. "Expenditures for housing and related urban development or planning within the U. S. bi-lateral assistance programs, though small initially, have been growing. In 1960, technical assistance, grant and development loan expenditures were about \$5 million, mainly in the form of technical services, but during the fiscal year 1961 the U.S. Development Loan Fund, which had theretofore made no loans in the housing field, loaned or obligated \$40 million for such projects, a considerable part of which has gone to encourage or expand thrift institutions which can attract local capital for housing financing. United States technical services and other assistance in fiscal year 1961 roughly equalled those of the preceding year. The new Alliance for Progress program promises to make substantial funds available, in loans

¹ The Editors of Architectural Forum, Building, U.S.A., pp. 70, McGraw-Hill, Inc., 1957.

and grants , for housing in Latin America , a large part of which will help promote aided self-help programs and thrift institutions .

"With recent expressions of interest by President Kennedy in housing aid , U. S. external assistance for housing in fiscal year 1962 will presumably show a rising trend in the years ahead." ¹

Finally , there is the possibility that the United States and the Soviet Union will agree to end the arms race . If this should happen , American industry would need new markets and housing the developing nations seems a logical area toward which to turn our industrial capacity .

And so The Problem has two sides : first , the very real problem of sheltering the two-thirds of the world population which is today inadequately housed ; secondly , the less urgent problem of broadening the markets for our industrial production .

¹Abrams , Charles , Housing and Urban Development Activities in the U.S. , report to U. N. conference on housing , 1962 .

"There is no getting away from it. It is technically possible to carry out the scientific revolution in India, Africa, Southeast Asia, Latin America, the Middle East within fifty years. There is no excuse for western man not to know this. And not to know that this is the one way out through the three menaces which stand in our way -- the H bomb war, over-population, the gap between the rich and the poor. This is one of the situations where the worst crime is innocence.

"Since the gap between the rich countries and the poor can be removed, it will be. If we are shortsighted, inept, incapable either of good-will or enlightened self interest, it may be removed to the accompaniment of war and starvation: But it will be. The questions are, how, and by whom. To those questions one can only give partial answers; but they may be enough to set us thinking. The scientific revolution on the world-scale needs, first and foremost, capital: capital in all forms, including capital machinery. The poor countries, until they have got beyond a certain point on the industrial curve, cannot accumulate that capital. That is why the gap between rich and poor is widening. The capital must come from outside."¹

¹ Snow, C.P., The Two Cultures and the Scientific Revolution, pp. 48-49, Cambridge University Press, 1959.

THE CONSIDERATIONS

The developing countries lie in a rather narrow band north and south of the equator. This location gives them a hot climate with long daylight hours. The rainfall and humidity varies from country to country, but in general is at one extreme or the other.

Basically, the problem is one of shelter from the rain and shade from the sun. A durable roof and the structure to support it are primary. A great part of the time is spent outdoors, and the people do not own a great deal of personal property or furniture, so the house need not be spacious. The social life centers around the dining table which serves for eating, drinking, cards, and conversation. The people are accustomed to using communal washing, laundry, and toilet facilities.

One of the great faults of many housing designs, however, is that they are not designed to improve or expand. Thus low-cost housing is doomed to deteriorate into a slum, and people whose circumstances improve move out because they find it impossible to improve their residence.

Another pattern that housing has followed, and probably will continue to follow, is that the absolutely destitute are never housed. Housing has seldom gone below the level of those who could afford to pay something for it, even though heavily subsidized. This would be particularly true in developing countries. Any new housing of sound construction would

be superior to that of many of the lower middle-class wage earners, however minimal it might be. And so the indigent will be left to claim the existing housing vacated by those who can help pay for new housing.

The migration to the cities is world-wide and the greatest need in housing is in the great population concentrations. Thus the system should adapt to multi-story, high-density complexes. The need for urban housing also reinforces the logic of an industrialized mass-produced system because of the volume in a single location.

In most developing countries the housing policy and programs are intended to use local materials and labor extensively, if not exclusively. Any design which does not include the use of some local materials and labor would probably be unacceptable.

Another consideration on the United States side is that the system would need a possible U. S. market. Mr. Hal Sparling of the Ford Motor Company recommended this as a criteria his company would demand. This is reasonable since there are many areas where such housing would be appropriate for itinerate farm workers and sub-standard urban housing. The system might also have a market as a "second" house now that the second car has become accepted.

THE PROGRAM

"The Ford Motor Company has, along with other large members of American industry, answered a plea from the Federal Government to investigate ways and means to absorb through diversification the manpower and material made available by the Progressive Disarmament Agreement recently made with Russia.

"They have come to you with a request for the design of a group of integrated building products, which they can manufacture and market in tremendous quantitiesbest utilizing their mass production skills and facilities. In view of our government's newly announced policies of international aid, they would like these products to be such that they would find a sizeable world market as well as a national one. They have selected two countries, therefore, Egypt and Uruguay, as test cases and have asked you to consider particularly their needs in addition to our own.

"In order to select from a number of interested applicants, they have asked you to present to them your first proposal in sketch and drawing form on March 7, 1962 so that they can select the team best qualified to undertake the final design on what they believe to be a major new market."

The above is a sketch problem from 4.43, The Industrialized House, from which this study has grown.

As the study has progressed it has evolved as a prototype system to exploit the widest possible variation in housing with the least number of parts, no

longer tied to any particular country.

THE DESIGN

The Polymer

The basic concept of this design is based on the premise that the various rooms of a residence may be reduced to a single spatial unit, and that one of these cells can house the kitchen, bath, mechanical core and circulation to the other rooms.

There are many logical advantages to this concept, particularly in the context of this problem. Pragmatically, it has the great advantage of exploiting the repetition of parts. It becomes possible to build a whole residence with a repetition of identical units. The saving in fabrication and erection time, as well as improvement of workmanship through familiarity becomes appreciable even in small complexes.

Architecturally, the concept is also valid in that the structure clearly articulates and organizes the interior space. Each cell is expressed clearly, both on the exterior and interior. Consider this clarity compared to a typical American house which is covered by a gable roof, which says nothing about how the interior space is divided.

This polymer concept is not without precedent. One recent example of a house made up of structural cells is that proposed by George Nelson and Gordon Chadwick. Possibly the most picturesque are the conical cells of Alberobello in Italy. "The houses of Alberobello (a national monument) and Locorotondo, set amidst the gentle rolling countryside of the little visited heel of the country, remind the architect once again that the four-square rectangle, although it might well answer the economy of today's building, is not the only solution to the shelter of man either in form or in function."¹

This polymer concept also solves one of the most troublesome problems of housing -- growth. Our houses are seldom planned to cope with the growing needs of a growing, changing family. This can be seen in the awkward additions and carport enclosures which appear before a tract housing development is three years old. If the rooms are separate structural units, there is no problem in adding these units. The unity of the architectural composition is also maintained in the manner of a "bunch of grapes", to use a phrase from Australian critic Robin Boyd.

¹Smith, G.E. Kidder, A.I.A., Italy Builds, pp. 32, Rheinhold, 1955.

Since the unity depends on a cluster of identical units the additional unit creates no discord.

The disadvantages of the concept lie in the spatial standardization of the room unit. Most of the hierarchy considered important to any group of spaces is lost. This is somewhat alleviated by closets reducing the bedrooms, and the possibility of a two-cell living room. However, this criticism is more academic and formal than practical. The actual spatial requirements of the activities which the various rooms house are not that different, and our addition of a foot to distinguish the master bedroom is more a gesture than a fulfillment of need. The only real problem is the living-dining area, and if these two cells are completely open to one another, as they are in most homes today, the double space is adequate for gracious dining and conversation, if not ping-pong or square dancing.

The Geometry

After investigation of various geometries it seems that the hexagon offers the most flexible, fullest extension of the polymer concept.

The greatest advantage of the hexagonal geometry is its clustering quality. It is possible to cluster six hexa-

gonal rooms around a hexagonal kitchen-bathroom core. And in dense complexes it is possible to arrange apartments of various sizes with no special conditions or violations of the geometry. It is also possible to ventilate and light six rooms with a single hexagonal well and any exterior hexagonal cell will have cross ventilation. This clustering advantage may also be seen in the mechanical core which is discussed later.

Because of the way hexagons cluster, great flexibility is possible in plans. This can be seen in the accompanying drawings. The various arrangements are almost endless and, I believe, a geometric progression of the number of sides (6-36) compared to the square (4-16).

A hexagon also encloses more space with less perimeter. In comparing the hexagon of this system with the most efficient orthogonal form, a square, we find that the hexagon encloses 142.8 sq. ft. with a perimeter of 44 ft. 6 in. A square enclosing the same area would have a perimeter of 47 ft. 9 in.

In further exploitation of the repetition of parts, the

hexagon will have $6/4$ more repetition than a square and the parts will be smaller and thus easier to handle.

One of the most pleasing advantages of the hexagon is in the polymer concept mentioned earlier. The addition or subtraction of one or more hexagonal cells does not disturb the composition. The remaining cluster of hexagons will always be symmetrical about one or more axes and thus pleasing.

The roof units of the system are hexagonal pyramids. This places the high point at the center of each cell where it should be and ventilates the space through a gravity ventilator. This pyramided form is exceptional strong structurally. Combined with the polymer concept they also produce a horizontal closure condition at all partitions and exterior walls, so that there are no triangular gable-end conditions. Yet they express the room unit in elevation, and help to drain the roof.

On the disadvantage side we have the enormous penalty imposed on any non-orthogonal system by centuries of custom in building trades, and manufactured building products. Doors, window, furniture are all made for 90° systems. This difficulty cannot be over-looked

and this hexagonal geometry could only be considered as an answer to a problem such as this, where the volume would more than compensate for the disadvantage.

In consideration of this conflict with standard 90° construction, this system offers a Y shaped column which brings all openings back to the 90° geometry thus solving the window, door and wall problems. Since the column is to be precast in concrete no penalty is paid for its shape.

In the mechanical core, kitchen cabinets, toilet fixtures and closets, which are to be mass produced by industry, the volume would completely absorb any tooling costs for the new geometry.

The furniture shown on the plans is mostly conventional and rectangular to illustrate that it can work quite well in a hexagon. The hexagon actually accepts the human form better than a rectangle, and except for the fact that it is made largely of orthogonally cut wood, there is no argument against hexagonal furniture.

The Core

The clustering of hexagons is used to advantage again in the mechanical core of the house. There are six fixtures which require water, drainage, or fuel piping: sink, stove, heater, lavatory, water closet and tub or shower. If these fixtures are hexagonal-shaped they can be clustered around a central hexagon which would contain all the piping, flue and vent.

Certainly such a mechanical core would be beyond the range of most housing in developing countries, but it should be planned into the system so that the standards of the housing could be easily raised with the prosperity of the occupants. In the lowest cost housing perhaps nothing would be provided but a sink and a combination stove-heater, the other four sides of the hexagon being blank panels. As the standard of living rises these blank panels would be replaced with the other fixtures.

The kitchen is developed in a U-shape from the plumbing core, and here again the kitchen is free to grow in several stages with the means of the home-owner.

The bathroom encloses the water closet and tub

but leaves the lavatory in what is circulation space. This places the most used fixture where it can be used at the same time as the other fixtures, and seems ideal for young families with children.

In the primitive forms of this system the only heated space would be the central one, heated by the stove. As the standard of the housing rises an upright oil or gas heater would replace the heating stove and exposed overhead ducts would carry the hot air to diffusers at the three corners of the central hexagon between the columns for heating the adjacent rooms.

The central interior location of the bathroom and kitchen is ideal functionally. It places the housewife in a position to control the activities of the household and is convenient for her many trips to the other rooms of the house. The central bath is easily accessible from any room in the house.

However, the interior location of the bath and kitchen do present a problem in the provision of light and ventilation. Since the developing countries lie in a relatively narrow band around the equator where they enjoy a long bright day, the problem of light becomes more nearly one of shade. The kitchen

borrows light from the dining space and this light would be adequate for the kitchen activities. It is assumed that the bathroom would come concurrently with rudimentary electric service and could be lighted artificially.

Ventilation looms as the biggest objection to an interior kitchen and bathroom. These are both odor producing rooms and the equatorial location of the developing countries adds to the problem. In the low cost forms of this system a gravity ventilator would be provided at the crown of the plumbing core. This would be helped in a higher standard house by a single exhaust fan in the ventilator.

The Materials

The one class of materials which is common to all developing countries is the family of cementitious and masonry materials. Buildings of permanence and value have traditionally been built of masonry and, lately, concrete. Even in countries with traditional wooden residential buildings the cement and masonry materials have been used for public buildings and public works because of their permanence and economy.

For these reasons the average family in a developing

country looks forward to owning a masonry or concrete house as an ideal. It also seems reasonable that the structure of a building, which is necessarily the heaviest part should be produced locally to avoid the penalty of shipment from the United States.

Thus the structural units of this design would be precast concrete. The in-filling of the walls could also be precast concrete or local masonry, depending on which proved more economical.

United States industry would still supply the reinforcing steel and the shear plates, moment connections and bolts for the system. It would also supply the metal forms for the roof, and floor panels, the columns and the edge beams. If the quantity were sufficient these forms could be highly sophisticated for automatic operation and high production, since there are so few elements in the system.

The mechanical core and the various accessories such as roof ventilators and louver panels would be produced in the United States and shipped to the developing country.

Here the material is steel, with various coatings.

Steel is the best choice since it is economical and durable for interior use and because the techniques for rolling, stamping and finishing steel are so highly developed in United States industry. The rolling, stamping and finishing would be done in the United States by highly automated mass-production techniques and the economies inherent in the long runs should be considerable. The finished parts would then be shipped knocked-down to save transport cost and assembled in the developing country with the cheap labor available there.

The Structure

Triangular precast concrete panels form the roof and floor structure. Since the system is designed for multi-story units and a suspended floor is necessary, the first floor would also be raised above the ground.

The floor panels are 2" thick with 6" x 6" - 10 x 10 ga. wire reinforcing. They have a 4 1/2" deep edge beam and three secondary ribs in a triangular pattern which are 3 1/2" deep. The panels would bolt together at the flanges with 3/4" bolts to insure the transfer of loads between panels. The bolt holes would be fitted with pins for lifting the panels. The floor panels weigh 800 lbs. in normal concrete or as little as

533 lbs. with light weight aggregates.

The roof panels are of similar design but need be only 1 1/2" thick, with the same edge beam and no secondary ribs. They would weigh 600 lbs. or as little as 400 lbs. with light weight aggregates.

In a system such as this the reinforcing steel would not exceed 1.5 lbs. per sq. ft. of area, so that in a single hexagonal room there would be approximately 225 lbs.

At the outside edges of the structure an additional edge beam is necessary to produce the strength occurring elsewhere in the structure at the double ribs of adjacent panels. This edge beam would be the same size as the normal edge beams (2 1/4" x 4 1/2", floor and 2 1/4" x 4", roof) and bolted to them typically. These edge beams would be erected first with the columns, to serve to plumb and stabilize the columns. When rooms were added, the edge beams would simply be unbolted and removed to allow the attachment of the additional triangular panels, then reused at the new edge.

At the corners of the triangular panels the point is

beveled off to produce openings for ventilation at the crown of the roof or electrical fixtures at the center of the intermediate floors, and space for grouting and connections at the columns. A stamped metal plate wraps around this corner of each triangle and would be placed in the forms at the precasting bed. When bolted these plates form a rigid connection at all apexes of the triangles. The ventilator or electrical fixture is a hexagonal ring which receives the blunt corners of the triangles so that it is possible to seat the panels. Two opposite roof panels would be placed first, leaning together at this ring. Then the other panels could be added in any order.

The pyramidal roof is a stable structure as long as the connections produce the tension ring at the bottom edge. It could be supported on only three columns. However, the floor system without the advantage of the inclined planes needs support at all exterior points, particularly in a multi-story system.

The exterior of the building would need columns and footings at all exterior points of the hexagons. The interior, however, because of the steel connections

and the transfer of loads to adjacent panels, would need columns at only three points on the hexagon. This frees three column locations around the mechanical core for air diffusers.

The Y shaped columns are sufficient to carry a building of five or six stories by changing the size of the reinforcing bars. They are 7 ft. 8 in. tall and each would weigh 570 lbs.

The footings vary with soil conditions and climate, but could often be precast and in combinations with the suspended floor should require a minimum of site leveling.

The infilling of the walls could be local masonry or precast concrete sandwich panels 4 1/2" thick with 1 1/2" rigid insulation in the center. There is a notch in the columns and beams which would accept a spline connection. In countries where high lateral loads such as earthquake or wind, the spline would need to be of heavy steel to resist the shear at the connection.

In assembling the structure it is assumed that lifting apparatus would be available. This is reasonable

since the operations of IBEC in Puerto Rican housing has shown that in any project of five hundred units lifts are economical. The triangular panels could be site assembled or they could be assembled at the plant into hexagons of six panels 13 ft. 7 in. across weighing 2820 lbs. maximum and transported and erected intact. In large projects a straddling strong back on movable track could best place units such as these.

In any case, in keeping with the industrialized idea it would be best to do most of the work at the casting site and a minimum in the field.

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THE BIBLIOGRAPHY

Bemis, Albert and John Burchard, 2nd., The Evolving House,
Technology Press of M. I. T., Cambridge, 1933

Goodman and Goodman, Communitas,
Vintage Books, New York, 1960

Kelly, Burnham, Design and the Production of Houses - Action,
McGraw-Hill, New York, 1959

Kelly, Burnham, The Prefabrication of Houses,
Technology Press of M. I. T., Cambridge, and Wiley, New York, 1951

Koch, Carl and Andy Lewis, At Home With Tomorrow,
Rinehart, New York, 1959

Rodwin, Lloyd, Housing and Economic Progress,
Harvard University Press and Technology Press, Cambridge, 1961

Snow, C. P., The Two Cultures and the Scientific Revolution,
Cambridge University Press, 1959

Atkinson, G. A., Mass Housing in Rapidly Developing Tropical Areas,
in The Town Planning Review, 1960.

U. N. Seminar of Building Research to Housing Programmes, Report, 1961