

A SYSTEM OF INDUSTRIALIZED HOUSING
FOR
DEVELOPING COUNTRIES

by

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Dear Sir:

A thesis entitled "A System of Industrialized Housing for Developing Countries" is hereby submitted in partial fulfillment of the requirements for the degree of Master of Architecture.

Respectfully submitted,

Julio Alberto Silva

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A System of Industrialized Housing

for Developing Countries

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Submitted to the Department of Architecture on
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ments for the degree of Master of Architecture.

GENERAL

Housing industrialization is nowadays one of the
most fascinating and positive fields of research for
an architect.

The world has arrived at a point where individual,
partial solutions to the problem are insufficient. We
need mass production housing. Millions of people all
over the world live in extremely poor conditions, and
it is our duty to help them to raise their standard of
living.

Industry can produce housing in the same way it
produces automobiles, that is, through a continuous
production of elements of high degree of industrializa-
tion which could be assembled subsequently.

The purpose of this thesis is to investigate how
industries such as Ford Motor Co. and Armco Steel could
contribute with their facilities in an approach to the
problem.

Thesis Supervisor: Carl Koch

I INTRODUCTION

Even though steel is an expensive material and its exportation to underdeveloped countries involves problems of taxes, the idea of producing tremendous quantities of panels that could be nested together occupying the minimum space and fabricated by a continuous process through the facilities of Ford Motor Co., shows us a phase of this field that could be the answer to an effective solution.

This approach to the problem has been considered from the point of view of providing shelter to these countries, that is, walls and roofs that can be assembled in an easy and rapid way within a space where the human being can live with dignity and hygiene.

This integrated system of building components for housing will include a certain number of elements with which we could tilt up the outside skin of a house. Only those elements which are in direct contact with the open air have been considered here.

A mechanical and plumbing equipment panel is also a member of the system.

Subsequently, the necessary insulation and interior partitions, will be added to this skin, and these will be studied in regard to the possibilities of the natural resources of each country.

Shipment facilities of the units above mentioned involves a problem of international agreement, between the American Government and the government of the underdeveloped country.

Intrinsically this field of study is extremely complex and an accurate study would include investigations in the social aspect which would indicate exactly which are the actual needs of each country.

II PROGRAM

The interest of this design has been to approach the maximum of generality for the system. With elements of the same shape, the system allows the erection of houses in practically any climate. The problems are different in each country. Some countries only have problems in regard to the roofing, and others need a complete shelter with the insulation varying upon the location of these countries. If designing is general, and not for a specific country, the market increases. With a large market, Ford Motor Co. can produce such tremendous quantities in a non stop process, reducing consequently the cost of the products.

By means of a thorough study of the systems that Ford Motor Co. employs in the manufacture of automobiles, the methods that Armco Steel uses in the manufacture of rolled sections, the author has arrived at the following conclusions:

Two methods are used to stiffen thin metal, which are:

- a) The rolling procedure
- b) The stamping procedure

THE ROLLING PROCEDURE consists of a continuous operation in which the sheet steel is shaped after passing through several rolls. The largest roll that Armco

Steel manufactures is 96" wide. This is the least expensive way to stiffen a thin sheet of metal. However, the use of rolled steel sheets in building panels have some disadvantages. Among them, the most important are:

1) The perfect finishing of only two edges, being necessary to find a solution for the other two edges. Connections between wall panels with floor and roof panels become then difficult, and generally, addition of a third piece is necessary for the finishing of the cut edge. A similar situation occurs when an opening is necessary such as windows or doors.

2) The rolled sheets of metal always have problems of rigidity in one direction.

THE STAMPING PROCEDURE requires more time. Panels need to be cut before the operation and it is a more expensive method compared with the rolling procedure. The steel sheet is placed in between a negative and a positive form, and then shaped in a two directional way as desired. The largest steel blank that Ford Motor Co. stamps is the roof of station wagons: 120" x 96".

The stamping method avoids the disadvantages mentioned above about the rolling system. The finishing of the four edges of a panel can be done as required by the design. Also stamping method allows to stiffen the steel sheet in a three dimensional combination of surfaces and edges.

By having a rational structural design, the author believes that economy can be reached by means of the use of thinner sheets, than the ones that would be required by a rolling method. As a result of these advantages, of perfect finishing and rigidity, the design has been planned through this method. In spite that a system of industrial components for housing such as this requires necessarily a minimum of flexibility, the standardization of the components allows the use of few different stamping machines. For instance, the main component for wall is a 6'-0" x 8'-0" panel that can adopt six different shapes, even when it is originally produced with only one machine. (Ill. 3)

All pieces removed from windows have a purpose in being used for the manufacture of other pieces.

THE ASSEMBLY LINE PROCEDURE consists of the manufacture of a complex product by means of several standardized operations. The mechanical and plumbing equipment panel of the system will be produced in an assembly line. Pipes and all kinds of connections will be included in a panel 6'-0" x 8'-0" x 1'-0", leaving the openings ready to connect lavatories, etc., which will be hung from the panel. (The details how this panel is joined and incorporated into the system can be seen in the drawings.)

The stamped wall and roof panels will be shipped to

the country of destination nested together.

All wall and roof panels have been designed to nest together.

Shipping space is a very important factor, and air space should be avoided in the package. In this way, thousands of panels will be shipped in a very easy way. (Ill. 1) and will contribute as a very positive effort in the mass production of houses.

In the country of destination there will be another plant working in complete integration with the system. The main function of this plant will be the manufacture of insulation slabs or panels.

This plant will also include some other minor operations such as the welding of some pieces. A crew of trained workers will also be necessary to teach and supervise the assembling and erection of the different parts from the package. Of course, the system will always be applied in places where hundreds or thousands of dwelling units are needed. A dry process of repeated operations will result in speed of erection. Wet process is avoided whenever possible. However, the foundation beam to footing connection and the floor finishing will be done on a wet basis.

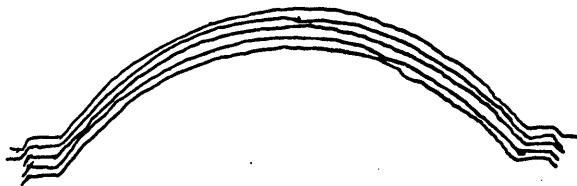
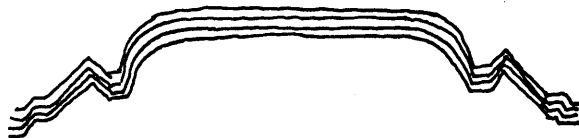
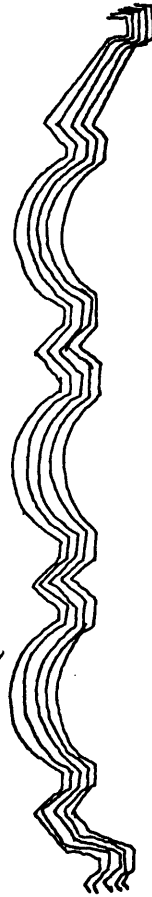


Illustration 1

III DESIGN

Abstract

A complex system of factors and limitations has to be handled to approach a design of this magnitude. First of all the standardized components must be integrated in a modular system. The basic module is 9 feet, which has been the result of the study of the minimum requirements for housing. A sub-module of 3 feet is also established in order to solve small problems.

Another limitation in the design is the largest steel blank that Ford Motor Co. manufactures by stamping procedure. This blank is used for the roof of station wagons and the size of the original steel sheet is 96" x 120".

The largest panel designed for the system is the roof panel 6' x 9' which could be produced with the same stamping machine that manufactures the roof of station wagons. This panel weighs 84 lbs.

The author believes that in an approach of this kind the building components must be designed in the largest size as possible, covering in only one operation the maximum of space. However, small pieces are also necessary to give flexibility to the design.

There is a long way between what we can consider flexibility and rigidity of an industrialized system. We must stop at a point of that path in which we presume we contemplate in a rational and integral way, the complex

number of limitations.

The depth of the panel is one limitation of the stamping procedure. Steel allows a certain degree of shape, but it is impossible sometimes to exaggerate the depth when the element is going to be stamped. When the panel is too deep or its surface is sloping down in an angle more than 45° , we run the risk to stretch the sheet of steel too much, reducing thus its thickness and diminishing its strength.

In a design such as this, the shape of the different components must have a strong consistency in order to be able to always keep the requirements of composition, aesthetics and integration of forms. Working on a modular basis, the repetition of joints and shapes maintaining the appropriate distance helps, if the purpose is to avoid extreme variety, but we have to face as well the opposite aspect, that is, monotony, not only in the design of the dwelling unit itself, but mainly when we are working in a design for a whole neighborhood.

The number of components necessarily has to be small in order to make economy, and at the same time it has to give the solution to many different situations.

The joints between panels are designed in a very general way, to be able to assemble any vertical component with any horizontal component with absolute freedom. The different pieces are bolted together, and bolts are placed also under a modular design.

All panels have been designed to nest together.

The shape and the general design of the different pieces has been the result of the observation of what Ford Motor Co. and Armco Steel produce nowadays. Besides, small model panels have been tested with load to prove the characteristics of rigidity.

Steel surfaces with curvature in only one direction lose rigidity when we are designing in a large scale such as this. A panel 6' x 9' designed with a simple curvature would need a thick gage of steel to be strong enough. Stiff edges combined with different curvatures help considerably to give rigidity, and this is a more rational use of the material.

The design of the components has been made according to the sub-division of large areas, thus obtaining stiff lines and profiting with the maximum of the advantages that the stamping procedure offers us. In this way, we will be able to use the least amount of material.

It is the author's opinion that steel, even when it is expensive, is one of the best materials to be used for the manufacturing of industrialized components for housing.

A maximum of perfection must be reached in the factory. Millions of times, the mass production of components, made by repetition of the same operation, is the origin of economy, perfection and good finishing.

The design has to be such, that will avoid all those operations in the building site that can be solved in the factory.

In accordance with statistics and research in Latin America countries, mainly in Puerto Rico, slum areas are a phenomenon that occurs in sub-urban areas. Most of Latin American cities are surrounded by belts of sub-standard dwelling units. The main problem in these cases is not in regard to the land, but it is the cost of the dwelling unit itself. Because of that, this design faces only the problem of single dwelling units and not the possibility of multi-story high solutions. In this way, the design becomes very light, simple to tilt up and without structure at all.

The panels are bolted together and a third piece of joint is always placed in between two panels. This third piece will help to give the general stability of the house, reinforcing all edges and carrying the load from the roof to the footings. In the case of the roofing system, the joint piece acts at the same time as a rain channel, keeping a continuous horizontal system that ends in the edges of the building.

Any panel of the house could be removed if necessary,

and design can be changed if desired to enlarge the dwelling.

The mechanical and plumbing equipment panel will have connections for a kitchen in one side and for a bathroom on the other. The assembly of this panel with roof, doors and floor is designed in detail, and its location can be in any part of the house.

The electrical equipment is located mainly by means of a continuous system of channels in the roof and door panels. Openings can be made in the wall insulation to connect wires.

The whole electrical system is designed under the same modular basis of the whole building.

Vertical components

All vertical components are 8 feet high. The edge conditions of these panels are different in the four sides.
(Ill. 2)

Generally with a roofing system in which load is directed toward the corners of the roofing panels, wall panels even when they are bearing, receive the bulk of load in the two vertical edges. In this way, the central area of the panel could be designed with more freedom, taking care only of general conditions of rigidity of the whole element

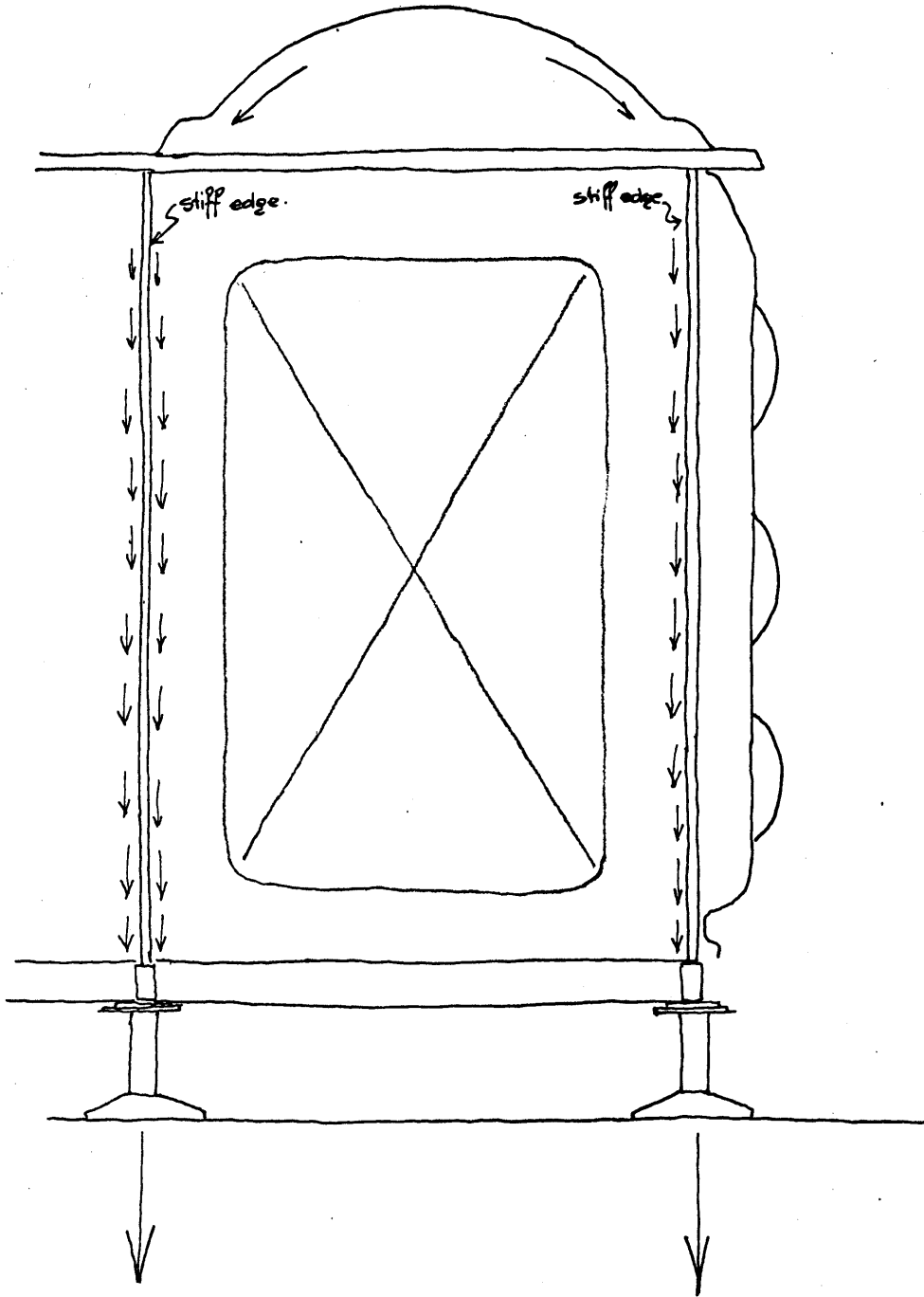


Illustration 2

and problems of the wind.

The upper edge was designed to receive the roof panel in a simple way and allows to run the rain water. The lower edge will be fastened to the foundation beam through a continuous strip of metal.

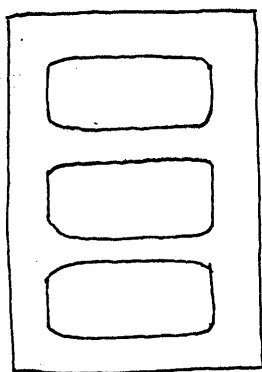
Dividing the vertical panel in smaller modulated areas allows to use the same type of component for wall as well as for windows, with the same stamping machine used in the manufacturing of the 6'-0" x 8'-0" wall panel, six different components can be obtained by removing some sections. (Ill. 3) Pieces of steel removed have a determined use for the manufacturing of other pieces. For instance, with the sheet removed from the component B (Ill. 3) it is possible to stamp two cross channel component for roofing joint.

The steel section removed from the component F of the same illustration is designed to manufacture exterior door components.

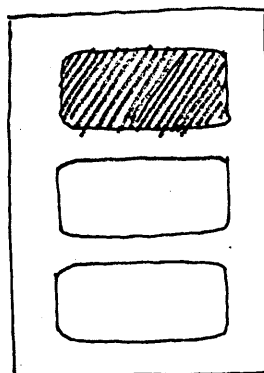
Horizontal components

These elements present the same edge condition in their four sides.

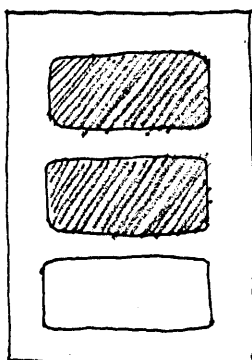
Besides limitations from the stamping procedure, roofing components must always present surfaces sloping down, in such a way, that water always runs off. A continuous system of



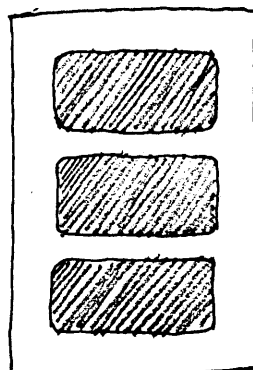
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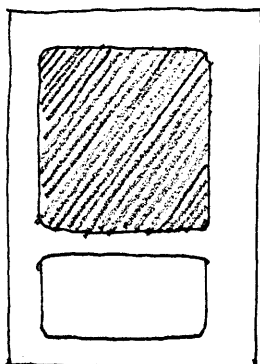
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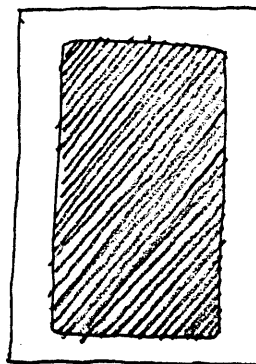
C



D



E



F

Illustration 3

rain channels is used to bear the roofing panels.

Two systems for roofs have been studied and tested. One of them, in spite that does not have much consistency in design with the rest of the elements, is a step ahead over the other (domes) because stiff edges help to maintain the shape with thin metal sheet.

A test made loading small models of both systems showed that the dome system has about half of the strength of the other one.

IV INSULATION

Insulation can be added to the panels with any thickness that is required.

Insulation slabs can be placed before or after to tilt up the panels in the building place. However, it will always be convenient to place the insulation before, in order to avoid operations when the building is under construction.

Loose stuff such as straw, wood chips, rice hulls can be spread while the panel is upside down lying on the floor. Then it could be sprayed with a very light epoxy or cement glue in order to keep it in place. A piece of cardboard or plastered board can be placed as a finishing.

Any size of insulation tiles can be obtained, but they are designed with the basic module.

Natural resources of the country will be considered for insulation purposes. Foam plaster, foam and cellular cement, and foam epoxy can be researched in order to improve conditions of strength and economy.

A research about epoxy resins was done along with this design in which the advantages of strong bonding have been used with different kind of fillers such as: expanded shale, vermiculite, fly ash, perlite, wood chips, wood saw dust, sisal fiber, asbestos fiber, fiber glass, etc.

It was also studied how foam epoxy plus some kind of filler can be combined to obtain a product with the minimum amount of resin.

V CONSTRUCTION PROCEDURE

The whole system of components will be such that all of them can be handled by two to four workers. The weight of the heaviest piece is 84 lb. and corresponds to the 6'-0" x 9'-0" roof panel.

Also floor slabs, even when they are designed in concrete will have a minimum weight of 100 lb. each.

As steel components are shaped to nest together, several dwelling units can be placed in one truck and transported to the building site.

The first operation will be to drill holes for footings in the ground, 2' deep. Concrete will fill holes and foundation steel components will be hung and liberated after concrete is set.

The leveling of the whole building is the next operation and the procedure consists on a series of filler plates placed on foundation footings. The amount of them will be variable from one to another in order to get a perfect horizontal level. After leveling, everything becomes modular and the perfection of factory finishing will become the basis for a good assembly of different pieces.

Foundation beams and concrete slab floor are placed in an absolutely dry way.

Then, exterior walls are tilt up with insulation, window frames and glasses previously fastened.

After floor and exterior walls are fastened, a layer of concrete or portland cement plus earth mortar will bind joints of foundation beams and will keep the floor rigid to wall connection.

Interior walls, partitions and plumbing equipment panel will then be fastened and construction is ready to receive U channels and roof panels, that is, the last operation.

Very light stairways are fastened to foundation beams in front of each exterior door.

VI CONCLUSION

No doubt, prefabrication and industrialization of building components will be a way of contributing to improve the housing problem in developing countries.

The author believes that an approach like this needs a background based on the social field. We are not going to improve the situation providing low cost housing, unless the task of teaching poor families how to live and what a minimum of hygiene means, is done before.

Steel is a fascinating field to work on industrialized components for housing. Stamping procedure gives us a way of obtaining a perfect finished product.

However, steel is a material with powerful means of expression. Shapes have to be studied and tested to reach the flexible, rational, economic, and aesthetics solution.

The procedures that Ford Motor Co. uses to stiffen thin metal sheet in the manufacture of automobiles, have been the basis of this design. By sub-dividing surfaces and through a test load process of different shapes, we are able to reach elements with a high degree of industrialization, and very light weight which can be nested together and shipped in a very easy way to different countries.

Housing is considered nowadays the major problem in any Latin American country and in many other countries of

the world. If it is in our hands to assist thousands of families to improve their living conditions, we must assume the responsibility of this task which is technical as well as social.

Mass production of housing components is, in the opinion of the author, one of the best ways to avoid the inconveniences of conventional methods of construction and to approach a quick solution for people with a very low standard of living.

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TEST OF THE ROOFING SYSTEM

Testing structures laboratory, Dept. of Building Engineering

24 concentrate loads distributed uniformly were applied to a 6'x9' polyvinyl chloride roof panel.

The model collapsed when the load reached 3/8 lb per point.

1) Find load per point. 1 point/sq.in.

$$\text{load/sq.in.} \times 144 = \text{load/sq.ft.}$$

$$3/8 \text{ lb} \times 144 = 54 \text{ psf} = \text{failure load for polyvinyl chloride model}$$

2) To get failure load for other materials at same scale multiply by elastic modulus ratio

$$54 \times \left(\frac{E_{\text{material}}}{E_{\text{polyvinyl chloride}}} \right)$$

$E_{\text{pvc}} = 500.000$
 $E_{\text{steel}} = 30.000.000$
 $E_{\text{alum}} = 10.000.000$

This gives load/sq.ft. at which model at this scale will fail

$$54 \times \frac{30.000.000}{500.000} = 3240 \text{ psf}$$

A prototype with exact proportions will fail at same load.

Our model is 6' wide and 15/1000" thick
full scale at 6' wide

$$\text{thickness must be: } \frac{6' \times 12}{6} \times \frac{15}{1000} = \frac{180}{1000} = 0.18''$$

3) If we wish to modify thickness of model we must multiply by the cube of the thickness ratios

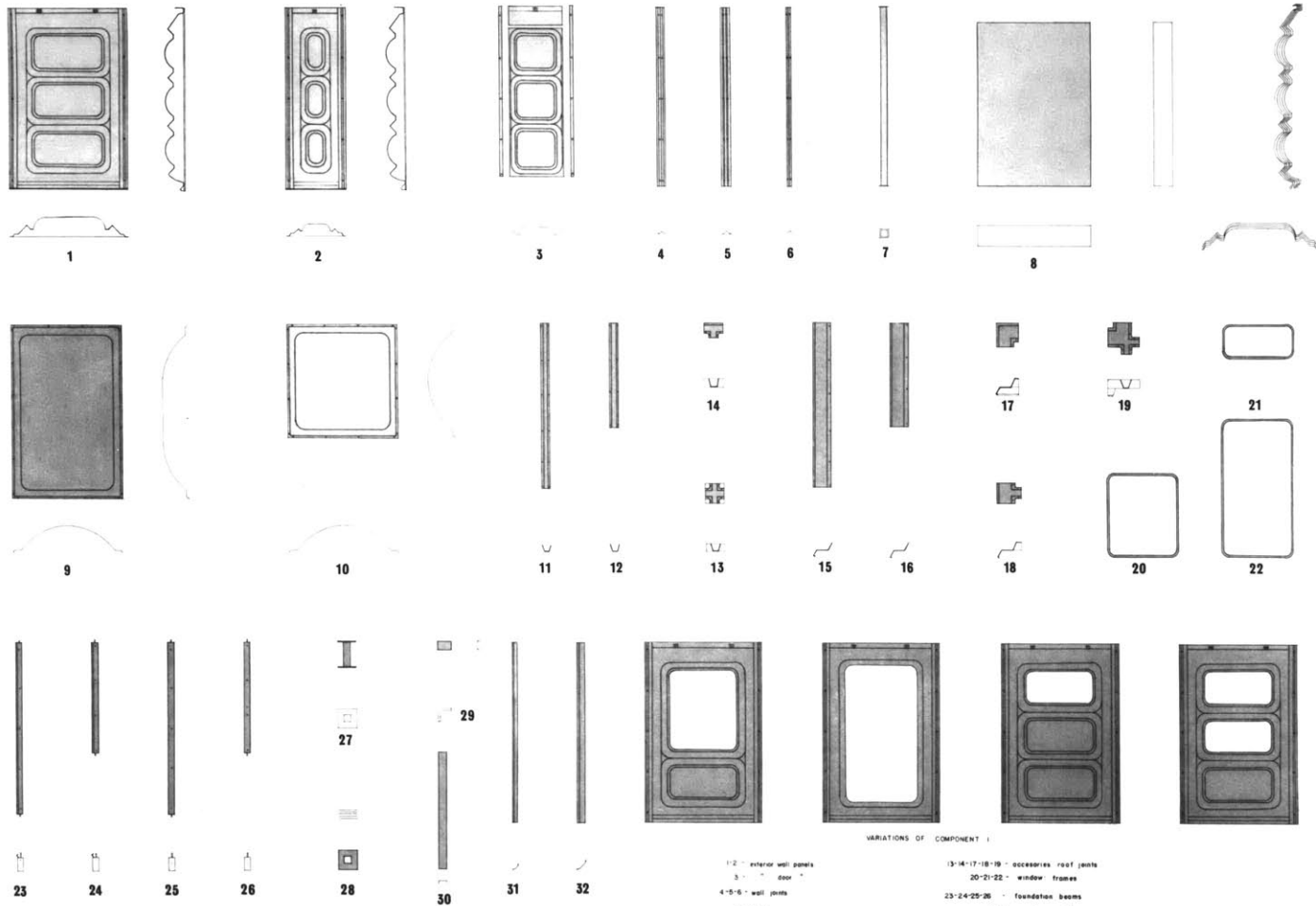
$$\text{ie. using 18 gage} = (0.05'')$$

$$\left(\frac{0.05}{0.18} \right)^3 = \frac{1}{47}$$

At 0.05" thickness (18 gage), the roof panel will have an ultimate load (failure) of:

$$\frac{1}{47} \times 3240 = 69 \text{ psf}$$

Using load factor = 2 (security) Final load = 34.5 psf



- VARIATIONS OF COMPONENT 1
- 1-2 - interior wall panels
 - 3 - door
 - 4-5-6 - wall joints
 - 7 - sill
 - 8 - mechanical and plumbing equipment panel
 - 9-10 - roof panels
 - 11-12-15-16 - joints
 - 13-14-17-18-19 - accessories roof joints
 - 20-21-22 - window frames
 - 23-24-25-26 - foundation beams
 - 27 - unit
 - 28 - filler plates for leveling
 - 29-30 - window finishing
 - 31-32 - interior joints

