Prefabrication in
Building Construction

by

Wilber E. Dehne

SCHOOL OF FORESTRY
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Building Construction

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Wilber E. Dehne

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Introduction

It is best to start with a clear conception of the term prefabrication. Prefabrication is the fabrication of any object before sending it to its destination.\(^{(9)}\)

The prefabrication of houses has been a popular subject of discussion for several years. Innumerable articles appear in periodicals and newspapers about prefabricated construction. It would appear that an impression is being made in the public mind that the problem of building better houses at a lower cost, and with great ease and rapidity, has been solved or is about to be solved by the prefabricated house and that the mass production of such houses is a new industry with all the possibilities of, for example, the automobile industry.

It is true that during recent years much study, research, and experimentation has been conducted by the construction industry as a whole with the aim of broadening the field of residential construction. The period has been characterized by a wide interest in the technical problems arising from the design and construction of houses. This interest, several years ago, took impetus from a recognition of the fact that new dwellings in the past were built largely for a limited market. It continued to develop from a realization that, if a mass production market for homes is to be developed, lower-priced homes must be built either through careful planning and a simplification of the required accommodations, or through economies effected in production which will permit the construction of houses at prices within the reach of a
greater proportion of the people. (2)

The apparent success of the automobile, radio, and other industries in creating a product capable of broad mass consumption has inspired experimenters in housing to attempt to produce in their field a product capable of similar broad use. The effort has followed many directions; from endeavors to introduce greater efficiency in customary trade operations to attempts to revolutionize both methods and materials.

Recognizing that a marked lowering of dwelling costs or a radical change in accepted materials and design would have an influence upon the level of value of existing property and upon the rate of obsolescence of existing dwellings, the Technical Division of the Federal Housing Administration has undertaken to accumulate information concerning new developments in dwelling construction. It maintains a file on new methods of construction and welcomes data on new developments in this particular field. With a view to keeping this information as up to date and complete as possible, where practicable, its engineers have conducted personal inspections.

For centuries houses have been built of wood, brick, stone, mortar, and plaster. The wood, brick, and stone have been brought to the site of the building operation in comparatively small sizes and there cut and trimmed by hand to fit the requirements of the particular building and then put together piece by piece—studding, beams, sheathing, siding, bricks, lath, and plaster—usually by hand. More recently mechanical work has followed a similar procedure.
This has necessitated the employment at the site of a large amount of hand labor, much of it skilled and highly specialized. For the specialist the amount of work on a single job is limited. To avoid having idle men on the payroll, the employment period has been the hour or day, men being laid off as soon as their services are not needed. This has resulted in a large amount of idle time and, to compensate for this, an hourly or daily wage, high in proportion to that paid in other lines of work.

The attack on the problem of building better and more cheaply is being made on four fronts: purchasing materials and equipment in larger quantities from fewer sources; factory fabrication of larger units and units combining more than one purpose so as to lessen the work of assembly and erection at the site; the use of materials supposedly better suited to their function and to factory fabrication; and employment of labor by the week instead of by the hour with a lower hourly wage in return for steadier employment.

To take advantage of the difference between wholesale and retail prices, a new middleman is appearing in the field. This new middleman is really a manufacturer of houses. He employs architects and engineers to design his houses, to study available materials and work out new methods of assembling them. He contracts in advance, usually directly, with manufacturers for his anticipated material and equipment requirements, based on his decisions to use certain materials and equipment in certain ways to produce a definite product.
He then offers for sale, not his services as do architects and contractors, not a piece of property consisting of house and land as do operative builders, but a house more or less complete and with varying degrees of standardization, which in a sense is a trade-marked product, and which is ready to erect on land owned by the purchaser. Erection may be handled by the manufacturer through local representatives, perhaps using their own erection crews, with local subcontractors for foundations and mechanical work, or the purchaser may make his own arrangements for erection.

Only a few concerns have adopted the practice of marketing a complete housing assembly. Many new types of structural enclosures and new methods of building them, however, have been prepared for commercial production. During recent years there has been a considerable increase in prefabricated items or parts of houses and progress has been made in the development and standardization of precut lumber to exact size and shape for specific purposes. There has also been considerable increase in the use of plywood, fibre board and composition boards in place of individual boards, plaster, and other finishing materials. (2)

The purpose of this thesis is to give the reader an idea of the steps being taken in the mass production of buildings, the advantages and disadvantages, and problems involved in drafting, mill construction, types of buildings, transportation, and erection.

Building Prefabrication is important because it gives a rapid construction of building and gives the customer a
sturdy, modernistic and economical building. The prefabricated building is usually of only one story but may be of two stories. The latest trend in architecture is a one story, low, rambling building. The prefabricated buildings are built along these lines, making them more desirable.

This thesis is based on my own conclusions and upon the facts obtained from interviews and literature of companies, corporations and research divisions without having had previous studies to use as a guide.
"The Johnson-Bilt House"

The C. D. Johnson Lumber Corporation at Toledo, Oregon, saw there was a demand for mass production of low-cost homes. They developed the "Johnson-Bilt" houses under the precision construction method.(1)

The precision construction method was developed after two years of study and research of mass production methods.

The C. D. Johnson Corporation decided upon two houses of different architectural design and classed them as classes I and II. Each class could be altered to give six different designs of each class. For instance, the design could be changed by putting in corner windows instead of the usual windows, changing the entrance from the right side of the house to the left side with a small porch or a porch that covered the entire front of the house, and by inverting the rooms within the house. The architectural drawings were drawn for all twelve houses and blue prints made. Detailed blue prints were made of all sections of each of the twelve houses. An example of a detailed blue print is shown in Figures 1, 1a, 2, and 2a of the window detail. All the drawings were standard drawings and the shop foreman could tell the number of pieces needed and how they were put together. This simplified machinery set-ups and standard material could be obtained readily without the extra cost of speciality items. In mass production of buildings, as it is with automobile manufacturers, a standard pattern must be decided upon and
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| Note:Parts same as above, except where changed on line below.
Figure 2a

Casement Window

Scale 3" = 1'0"
manufactured. When the manufacturer lets the public start changing his standard patterns, a high cost for the change in drafting and machine set-ups results. The design must be changed from the rough draft to the detailed blue print that is sent to the shop foreman and this is an expensive procedure.

When one of the standard houses was decided upon, all the salesman had to do was tell the shop foreman. The foreman looked at his detailed blue prints which were all ready on file at the shop and began building. The use of "standard" above means the house that C. D. Johnson Corporation used as their standard house or the house they were producing by mass production.

The houses were constructed using the Western Platform Frame. This type of construction was used because of the short length of studs and the wall section could be set on the sub-floor.

Prefabrication gives the company a chance to use up short length lumber that otherwise is of little value.

The wall sections were built on a table in a horizontal position and some of these were 50 feet long. The wall sections were complete to and including the interior finish. Some of the sections were covered with wall paper and later covered with a heavy bond paper for transportation. The bond paper was removed from the walls at the building site and used between the sub-floor and the flooring.

The walls started with 2" x 4" studs, then a layer of tar paper, shiplap, and siding. The interior had a layer of tar
paper and then the plywood finish. It was found through experience that the ceiling swelled and shrank more than the walls. This was remedied by using Johns Mansville ceiling tile. It came in sheets 16" x 16" x \( \frac{3}{4} \)" and was the best insulation material that could be obtained. These sheets were made from pressed wood pulp having an overlap of \( \frac{1}{2} \) inch. This overlap allowed the ceiling to shrink and swell without showing an opening. This tile served two purposes; that of insulation and of finish.(6)

The house sections were transported by a special low built trailer which had a rack to hold the sections. A special truck with a 36 foot crane was used to place the sections in position at the building site. These wall sections were complete with windows in place and doors hung. In less than three days, on an average, the house could be covered and ready for finishing.

"Several times a 30 foot wall section was dropped, knocking a piece from the foundation and it didn't rack. The house is stronger than the average dwelling constructed at the site.(5)

The order in which the wall sections are transported is shown in Figure 3. These sections are placed in the trailer in the order of their erection.

It must be understood that the foundation must be all ready built and the sub-floor laid before the house is brought to the site.

Figure 4 shows a few of the joints that are used because they simplify assimilation of the wall sections at the build-
A rough sketch of the walls in position after removal from the trailer indicating the order in which they were erected.

The trailer rack

The order in which the wall sections are transported corresponding to erection.
Common O.S. Corner:

- A

- B

Common partition splice:

- Two, 2" x 4" caps

- Studs inside wall

- a', b', c', d'
ing site. A in Figure 4 shows a common outside corner about to go into place. This view is looking down from above. It shows wall section (a) with shiplap and siding extended to cover section (b). The siding in (b) is extended to cover the shiplap of (a). This leaves a square notch on the outside wall which would be filled with a piece of quarter-round. The plywood of section (b) runs through to the shiplap making a smooth inside corner which would need a quarter-round to cover any noticeable cracks. A' shows how the two 2" x 4" caps hold the top of the walls together. (a') and (b') are the same sections as (a) and (b) respectively, but it only shows the caps on the studs. The top cap of section (a) is long enough to reach over section (b) where the top cap is short of the cap beneath by the width of a 2" x 4". This 2" x 4" affords a nailing surface.

Part B of Figure 4 shows how a partition section is made fast to another wall. The stud in the partition (c) is set far enough in to allow the spline to go inside the wall and the plywood can be nailed to the spline. Wherever a spline is to be nailed to the plywood, two 2" x 4" studs are placed inside the wall as illustrated in (d). This makes a sturdy place to fasten the spline and in turn a sturdy place to fasten the partition. The plywood passes behind the spline, thus making a smooth finish inside.

Figure 5 shows a completed prefabricated house made by the C. D. Johnson Corporation.

The first house built was F. H. A. inspected and approved.
A completed prefabricated house
by C. D. Johnson Corporation.
Some of the features of the house included washable walls, insulation throughout, air conditioning, complete dry-built, hardwood floors, covered linoleum, factory-built cabinets, colored plumbing fixtures, acoustical tile ceilings (Johns Mansville Ceiling Tile), completely gas equipped including a modern gas furnace, and automatic storage heater.

Johnson models ranged from $1,875 to $5,000 in cost.

The mass production of houses by the Johnson Corporation failed because:

1. Special equipment had to be purchased for transportation and erection at the site making for higher cost.

2. Expensive licenses were needed for this transportation equipment.

3. The purchasers were unable to become accustomed to the idea of buying homes in the same manner as they would purchase automobiles. Requests were continually being made for changes in the standard house.

4. These changes, if made, incurred a high cost in the drafting room and in machine set-ups.

5. Separate contracts had to be let for the construction of foundation, chimneys, and fireplace.
CHAPTER II

The Johnson Ply-built House

This house is entirely made of plywood and is still in the experimental stage. Several structures have been built but the buildings are purely experimental as yet. The plan of this house can readily be changed because of the ease of adapting plywood to a new design. All the walls are done in full sheets which greatly reduces the cost of changing a design.

Figure 6 show typical wall intersections of this newly designed house. Figure 7 is a window detail, Figure 8 is a door detail, Figure 9 shows typical sections of outside and inside walls, and Figure 10 shows a detailed drawing of the interior partitions and their order of placement.

With the frame built, it was a comparatively simple matter and a short job to place the exterior walls because of the size of the plywood panels. These panels are of Douglas-fir, bonded with phenol resin instead of glue. In a winters exposure, the exterior veneer on each panel checked from weather, but this checking did not go beyond that one layer of veneer--that it did not penetrate the bond. The plywood walls with rock wool insulation proved to have excellent insulating qualities. The company is looking forward to the time that people will become conscious of the beautiful homes that can be built from plywood.(5)
Figure 6

**Junction - Inside to Outside Wall**

**Junction - Inside to Inside Wall**

**Outside Wall Corner Detail**

**Inside Wall Corner**

**Plans of Typical Wall Intersections**
CHAPTER III

Prefabricated House System Under Development by the
Forest Products Laboratory, Madison, Wisconsin

The house described in this chapter is a basic example
of a system of prefabricated all-wood construction developed
in line with modern structural research and erected on the
Laboratory's grounds for further experiment and development.
It is not being produced commercially at the present time.
If houses based on this system are produced commercially in
mass quantities, it is not known at what price they can be
sold.

The house herein described is the second experimental
prefabricated house developed by the Laboratory -- the first
having been erected in 1935. It is a one-story building,
constructed largely of plywood, and contains a living room,
kitchen, two bedrooms, bathroom, and utility room, as well
as adequate closet space. In it are incorporated the Lab-
oratory's latest results in housing research which are based
in part on experiments with the earlier structure.

The findings include among other things the use of ply-
wood made up with synthetic-resin adhesive, and provision of
moisture barriers within wall, floor, and roof panels. Other
interesting features of the new construction are plywood
floors with 1/8-inch hardwood veneer as wearing surface and
the use of mineral insulation material to increase fire re-
sistance as well as to provide necessary heat and sound
insulation.
This house serves both as an example of the prefabricated method of all-wood construction and as a test of its permanency under actual weather conditions. The house also affords a means of obtaining additional research information on various factors such as the efficiency of the moisture barriers and thermal insulation used.

The system is based on the use of standard units, sections, or panels to be made in large quantities by factory methods, and then assembled quickly and without waste on the site. Its ultimate success will depend on good workmanship and technique in the construction of the plywood and house units, accurate dimensions of units, and efficient painting practice.(3)

Each panel consists of two plywood faces glued to either side of an inner structural framework to form what is virtually a box girder. While the use of plywood is much in evidence it is interesting to note that the number of board feet of lumber approximates the number of square feet of plywood.

The differences between the Laboratory's panel system and the conventional type of construction are marked. To choose an example at random, in the conventional type of floor construction the subfloor and finish floor are nailed to relatively deep joists. The subfloor is nailed diagonally in order to stiffen the building, but it is of little benefit to the strength of the floor framework. In contrast to the foregoing, each panel in the Laboratory's system has a complete and continuous rigid joint between the plywood and the framework formed by the glue between the plywood and joists. This causes the entire panel to act as a unit like a box.
girder and as a result the floor panels will deflect only about one-quarter as much under a given load as the joists acting alone.

A typical wall section, 4 by 8 feet in area, is shown in details in Figure 11. The exterior panels are 3 inches in thickness and consist of 3/8-inch three-ply plywood on the outside, and 1/4-inch three-ply plywood on the inside. The framework consists of vertical members made of 1-inch material 2-3/8 inches wide, spaced approximately 12 inches apart with two end headers, to which the plywood faces are glued. The partition panels are also 4 by 8 feet. Both faces of the partition panels are, however, of 1/4-inch plywood, and the vertical members are 2-1/2 inches wide, the overall thickness being 3 inches.

Experiments indicate that these panels when tested as a beam require a load of more than 200 pounds per square foot to cause failure. A 60-mile wind has a pressure of about 12 pounds per square foot, which is approximately one-seventeenth the load required to break the panel.

The plywood projects beyond the framework of the panel forming a continuous right-angle groove 2-3/8 inches wide and 1-1/4 inches deep entirely around the panel. A portion of the sill fits up into this groove. A 2-1/2 by 2-3/8-inch solid vertical member is fitted into the grooves on the sides of the adjacent wall panels. This vertical member serves as a connecting piece between panels, and also carries a part of the roof and floor loads. At the roof a strip glued to the
Floor plan of new prefabricated wood house

Details of construction of new prefabricated plywood house developed at the Forest Products Laboratory, Madison, Wis.
roof panel fits down into the groove at the top of the panel as shown in the details. After assembly the wall, floor, and roof panels are securely fastened by screws or nails to those parts which fit into the groove, tying wall, foundation, and roof together. (3)

The edges of the face of the panel forming the interior house wall are beveled to form a V-joint when the panels are assembled. The panels forming the exterior surface are beveled on the outside and inside edges, the outside bevel to form a V-joint similar to that for the interior wall surfaces, but slightly opened, and the inside bevel to form a pocket for mastic which is placed between the panels directly after erection. This pocket permits a sufficient amount of mastic to be placed between the panels so that it will retain its plasticity, and thereby make a tight and permanent seal against the entrance of moisture and infiltration of air at the exterior panel joints.

The floor panels are 4 feet wide and 12 feet long. The upper face is 5/8-inch plywood of five plies, and the lower face is 3/8-inch plywood of three plies. These faces are glued to a structural framework consisting of three nominal 2 by 6-inch members spaced approximately 24 inches apart, with end headers. All parts of the panels act as a unit and therefore the panels can be substituted for the usual 2 by 10-inch joists spaced 16 inches apart as ordinarily used in house construction.

The lateral edges of the floor panels are grooved to
permit a spline connection for the distribution of weight to adjacent panels. When panels of this type are tested as a beam over a 13-1/2-foot span, more than 300 pounds per square foot are required to cause failure. Accordingly, the panels far exceed in strength any loads normally put upon them.

Except in the kitchen and the utility room, the upper 5/8-inch plywood is faced with birch 1/8-inch thick to form the wearing and finished floor surface. This construction eliminates the necessity of putting a finished floor over a subfloor as in ordinary construction.

The roof panels are similar to the floor panels in construction. The top plywood covering of the roof panels was cut back 1/4-inch to allow a groove between the panels, and this groove was filled with a caulking compound. With this size of groove it is believed that the caulking compound in the joint will remain plastic for a long time and, therefore, form a better and more permanent seal. After the joints were filled, the entire roof was covered with a material similar to a thin caulking compound.

All exterior surfaces of the house described here are of hot-pressed resin-bonded plywood. The use of plywood in the past for outside permanent construction has not always proved satisfactory because the glues available were not sufficiently resistant to weathering. With the introduction of the resin type of glues this situation has changed. At present plywood glued with the hot-pressed resin glues is being used more and more for outside use with every indication that it will withstand the weather indefinitely without
the plies separating, provided ordinary care such as painting the edges and surfaces is used. Resin-bonded plywood has also been used for interior surfaces because of its somewhat greater fire resistance which will be mentioned more in detail later.

Coincident with the introduction during recent years of more moisture into homes by means of humidifying apparatus, houses are also being made tighter by the use of storm windows, weather strips, and the more general use of insulation within the walls and roofs. In houses loosely constructed, the moisture-laden air, which flows from the warm inside toward the outside, is easily carried away; however, in houses with good insulation and tighter construction, either of conventional type or prefabricated, the moisture is not easily carried away, and when it reaches the cooler areas within the wall it may condense. Over extended periods considerable moisture may accumulate, the insulation may become wet, and its efficiency may be greatly reduced. Even when warm weather arrives the moisture disappears slowly and may make conditions favorable for rust, mold, and decay. Many paint problems, such as the peeling of outside paint, also arise from the accumulation of moisture within the walls. Obviously it is very important to prevent such conditions, and, therefore, moisture barriers have been used in the outside walls of this house.(3)

The moisture barriers used consist of asphalt-impregnated and coated paper weighing 50 pounds per 500 square feet. The barriers are placed within the panel and against the back
face of the inner walls, against the back of the upper face of the floor panels, and against the back of the lower face of the roof panels; that is, in all cases the moisture barriers are placed within the panels and against the back of the face nearest the inside of the room.

A moisture barrier is placed in each space between framing members, and consists of a single piece of paper so folded as to fit snugly against the plywood face and along the sides of the framing members. Those parts of the sides of framing members that are in contact with the moisture barriers were given a brush coating of asphalt paint just before the barrier was placed, after which the barriers were held to the framing members with wire staples at intervals of not more than 6 inches to keep the paper tightly against the framing members and in contact with the fresh asphalt paint.

The space within the wall panels is entirely filled with a mineral wool insulation giving a coefficient of heat transmission for the wall of approximately 0.13. This is superior to ordinary construction with 1/2-inch of blanket insulation.

In addition, the use of large plywood sheets in wall panels is very effective in making the structure wind tight. Insulation has also been placed in the partition walls for sound deadening purposes.

The floor panels are insulated with nominal 2-inch mineral wool bats and the roof panels with 4-inch bats.

Fire tests of plywood at the Forest Products Laboratory show that the plies of vegetable-glued plywood separ-
ate while burning, whereas the plies of resin-bonded plywood do not. Resin-bonded plywood will therefore give somewhat greater resistance to fire than will plywood glued with a vegetable glue. On this account, and also because it offers somewhat greater resistance to the passage of moisture, resin-bonded plywood was selected for the inside walls as well as the outside walls.

To obtain greater fire resistance a mineral wool of high density was selected as an insulating material.

The floor area of the house is 24 by 36 feet. The house includes a 12 by 20 foot living room, a kitchen, two bedrooms, a bath, connecting halls, and a utility room. In addition there is a coat closet and a linen closet off the main hall, two closets in the larger bedroom, and a wardrobe closet in the smaller bedroom. Placed close to the house there is also a large garage, with a space at one end partitioned off for storage. The garage is connected to the house by a roof made of roof panels.

The walls of the living room are of natural finished birch, while the ceiling is painted a light color. The floors are of birch-faced plywood, as are all other floors, except the kitchen and utility room, which are of Douglas fir plywood. The walls of the hall are also of birch, finished natural. The walls of the other rooms are of Douglas fir, painted.

The house is heated with an oil burner. A warm air-forced circulation system is used, and the heating ducts are
confined mostly to that portion of the hall connecting the various rooms. This portion of the hall has a lowered ceiling to accommodate the ducts. A post and plank foundation of creosoted wood has been used.

In prefabricated houses there is a decided tendency toward one-story homes. It is, however, both practical and feasible to erect two-story houses with the Laboratory's prefabricated panel system.

Figure 12 shows the four steps in the erection of this prefabricated wood house.
Four steps in erection of prefabricated wood house
CHAPTER IV
The Development and Growth of Prefabricated Panelized Buildings

Although the Civilian Conservation Corps, one of the most popular and successful relief agencies of the Government, was conceived and designed to rehabilitate the youth of the nation, it is, surprisingly enough, responsible for a tremendous impetus in the development of low-cost prefabricated panelized housing.

On March 31, 1933, the President authorized the establishment of the CCC. The War Department, as a cooperating agency, was charged with administrative functions and so-called "housekeeping" responsibilities, such as clothing, feeding, medical care, camp management, housing, etc. In less than two weeks, enrollees moved into tents at the first camp near Luray, Virginia.

The CCC was first housed in tents but as the corps were popular and were to be continued into winter months, more adequate shelter was needed. Wooden buildings were erected at once to provide minimum accommodations.

Due to the urgent necessity for speed, construction of shelter was decentralized and the responsibility for the construction was placed on field agencies. The degree of decentralization varied greatly within the several Corps areas. Some Corps areas retained centralized control, some authorized district and individual camp commanders to conduct construction, while still others utilized a combination of these methods. Necessarily, uniform construction standards were lacking.
It can easily be understood that construction in any section of the country would radically be different from that of another because of the local differences. Nevertheless, all provided reasonably adequate shelter for the 300,000 men.

Much of the material used, such as lumber, caused considerable criticism. As can well be imagined, such a tremendous amount of wooden shelter required a large volume of lumber, for which locally available seasoned stocks were totally inadequate. Due to this shortage large quantities of unseasoned lumber were utilized, and shrinkage defects naturally followed within a very short time. Further, grades were not always well selected, with the result that some structures were not as satisfactory as they might otherwise have been, while others were unduly refined. It was apparent that greater control over construction, as well as better facilities would be required to house the CCC and its equipment.

It also developed that a camp, when once established, could not be maintained at one location indefinitely. Through experience, it was found uneconomical to operate a work project at a greater distance than thirty and forty miles from the camp. Therefore, when the work on a project was exhausted or completed, moves to accommodate work locations were necessary. The original structures were not adapted to moving and, as a matter of fact, only a few attempts to dismantle and re-erect them were made. These proved costly, both from the standpoint of labor costs involved and the large amount of replacement of damaged materials required.
As the cost of camp construction is the greatest single item of expense in establishing a CCC Camp, the economic waste occasioned by the abandonment of such a large number of camps was a matter of grave concern. Recognizing the need for better buildings as well as for a greater degree of standardization and mobility, the authorities of the Fourth Corps Area started experiments early in the Spring of 1934, looking toward the development of a sturdy housing unit of prefabricated panelized construction which could be assembled through the simple means of bolts and lag screws which would permit easy dismantling. The desirable unit necessarily had to meet the following requirements: first, simplicity of design (minimum number of parts); second, interchangeability of parts; third, sturdiness; and, lastly, ease of fabrication. It had further to be economical, reasonably comfortable and weather-tight; a type of construction of universal application, easy to erect and dismantle, with units capable of being transported by normal means - truck, rail and water - and yielding the maximum salvage upon being dismantled.(8)

Many panel assemblies were tried. Most of them were discarded. Finally an arrangement of floor, wall, roof and partition panels was evolved which gave promise of simple fabrication and ultimate economy. The roof panel presented the greatest difficulty, which was solved through the combination of the functions of a roof surface with those of the top chord of a truss. In other words, the rafters which constitute integral parts of roof panels were designed so
that they were at once used as members of roof panels and as top chords of trusses spaced ten feet apart. This design had to be worked out largely by the application of intelligent engineering judgment, since the combination of stresses developed in the unique arrangement of structural members was not subject to simple rational analysis. Further, the truss connections required more strength than could be developed by bolts. Timber connectors were indicated and their use provided adequate joint strength.

Information was received May 11, 1938, of the establishment of a CCC Camp in Alaska, which would require three buildings. These buildings were contracted for, prefabricated and delivered to the dock at Seattle, ready for loading on a transport within seven days. This shows the speed at which prefabricated buildings can be constructed. It was later stated that these buildings stood the cold weather, heavy snows, etc. without any discomfort to the men.

In addition to the economical advantages of panelized camp buildings, which cannot be disregarded, the experience records of the past five years have established the fact that this type of temporary building is more sturdy than the "built-in-place" type.(8) The proof has been established throughout the cyclone and hurricane belts of the country where hundreds of camps have been subjected to winds and freakish storms of high intensities. There are numerous recorded instances of portable structures with men inside having been lifted by wind off foundation posts with absolutely
no resultant damage of any kind except for the labor incidental to dismantling and re-erecting on foundations.

The question of heating these buildings had naturally presented itself and was solved through insulation. Standard insulation board was installed on the outside of studding beneath the wall siding and held securely in place with the same nails which secured the siding. It forms an integral part of the panel, is fully and thoroughly protected against damage and completely preserves the demountable features of the building. As insulated above, two or three stoves are adequate for heating a 100-foot or 120-foot building, even in severe weather in the Northern States. These structures, therefore, proved entirely satisfactory in all sections against the heat and winds of the South, and the cold, ice and snows of the North.

Loading tests were conducted on several of these buildings, which consisted of piling bags of sand on 10-foot sections of the roof, which were unbolted from the rest of the panels and were so located that no support would be developed by end walls or partition panels. Loading was continued until failure, and deformation measurements were obtained in the building section during loading. Independent sections tested supported 87.5 lbs. per square foot of horizontal projected roof area before failure. The results of these tests are considered to be quite important in that they provide adequate assurance that the unique panelized roof structure used is sound from an engineering standpoint and that
the specifications for the lumber are entirely satisfactory.

The panel type prefabricated structure is a "natural" for the utilization of "shorts" and "factory waste". In the process of sawing because of knots, wind shakes and other blemishes.

The foregoing paragraphs give a brief description of the development of the standard demountable CCC Camp building. The discussion, however, will not be complete without some consideration of the adaptability of this system of construction to other uses. For example, the over-worked farms of many regions of the South and Southwest have long been notorious for the dilapidated tenant houses and farm structures prevalent in that area. It is entirely practicable to replace tumble-down tenant shacks with 20' x 20', 20' x 30', and 20' x 40' cottages built of standard panelized camp buildings, dressed-up by the addition of a prefabricated panelized porch and shutters and a coat of paint, thereby improving both living conditions and appearances at a cost well within the means of the occupants. Made in various styles, the portable houses allow wide enough choice of model to maintain the full home individuality of every farmer who buys one.

Figure 13 shows the plans for the standard CCC buildings described in this chapter.
CHAPTER V

Panelized Houses for the South Pole

On previous trips to the South Pole the expedition used ice houses somewhat like the Eskimos but this trip is to last several years, and the members of the expedition needed better homes to house them during their dreary stay.

It was, therefore, no mean task dropped into the lap of Major Andre L. Violante of the War Department to design buildings to house this Expedition that would or could overcome the many obstacles to be encountered on a trip of this nature. The houses would have to be compact, for there is only limited stowage space aboard ship. They could not be too heavy to be handled by hand, because of the absence of mechanical devices. Severe weather conditions are sure to be encountered at the edge of the ice and above all, the houses must be something that would stand up under the stresses imposed by temperatures as low as 150 degrees below zero; wind velocity of over a hundred miles per hour, and ultimately a snow and ice load of up to fifteen feet above the roof of the structure or 300 lbs. per square foot in mid-winter.

As was previously stated in Chapter IV, Major Violante was Constructing Quartermaster of the War Department in the Fourth Corps Area for several years before going to Washington, and is credited with having developed while there plans and specifications for the completely prefabricated portable buildings now being used throughout the country for housing the Civilian Conservation Corps.
While studying the problem of housing the South Pole party, Major Violante remembered an incident out in West Florida during the late summer of 1936. Stiff breezes suddenly blowing in from the Caribbean moved a CCC recreational building a considerable distance. Although occupied by a number of enrollees at the time, none of the men were injured, and the building was not damaged, other than the disturbing of its foundation supports. Major Violante concluded that if this same general plan of panelized portable construction could be adapted to meet conditions at the South Pole, his troubles would be over.

A remarkable characteristic of Long Leaf Yellow Pine is its resistance to moisture—once seasoned, it absorbs very little moisture. This was the material selected for the buildings to go to the South Pole.(7)

All outside wall, gable and end panels were sheathed solidly with tongue and groove Long Leaf Yellow Pine on 2" x 4" studs, or skeleton frame members, then reversed, and the interior side covered with a solid sheet of 3/8" Douglas-fir plywood, but before fastening, all the dead air space between the studs was completely filled with Mineral Wool Felt, four inches thick. The roof panels were similarly constructed 4 feet wide by 16 feet long, except made up of 2" x 6" members, and containing six inches of Mineral Wool Felt insulation. No provision was made for windows, however, a three-glass sky-light was built into every other roof panel to admit light although probably to be covered with snow a good part of the time. Each building has two heavy door
panels, also insulated, and with composition gaskets all round. This is the same type of door you find in large cold storage installations, except that it functions in an opposite manner, keeping the cold out rather than in. The floor assembly consisted of double sheathed panels, also lined with mineral wool, with a second false floor on top, separated by twelve inch timber spacers, affording twelve inches of dead air insulating space between the main floor resting on the ice foundation and the service room floor. All panels were fabricated in jigs made of heavy angle iron, so when the different panels were assembled they would fit perfectly, and form a solid panel throughout all the dimensions of the building; the panel members being bored so that each panel could be bolted at several points to the next adjoining panel. All roof trusses, braces, supports, and roof panels were fashioned at the joints to receive standard 4-inch TECO ring connectors, half the depth of the connector being imbedded in each contacting member, with a bolt through the center. By this unique modern method of timber connector construction it is possible to increase the strength value of small timber dimensions several times, and build into a structure with small light sizes the same load-bearing limits requiring much larger sizes under ordinary methods of construction. The interior of the bunk houses or living quarters was outfitted in Pull-car style; a row of double-deck berths along both sides of the building, with partitions between. This gives each two men a semiprivate room measuring about 4 feet by 8 feet, with a collapsible writing desk attached to one.
of the partition walls. Every effort was made to make these quarters as comfortable and homelike as possible.(7)

When fabrication was completed, and ready for shipment, Major Violante, with several members of the Expedition, flew down to Shamrock, Florida, and with their own hands erected one of the larger buildings to see for sure they would go together, and to get ideas as to how they would do these things after they reached their South Polar destination. The work was completed within 48 hours.

It must be understood that these houses were built to stand extreme stresses but it illustrates what can be done with prefabricated panelized structures.

Figure 14 shows a few of the views of the houses sent to the South Pole.
Top: Interior view of the prefabricated house built by Putman Lumber Co., Shamrock, Fla., insulated to withstand frigid zone temperatures. Center: Two-deck bunks with collapsible writing desks. Bottom: Exterior view showing the insulating material being put in place.
SUMMARY

Findings.
It was found that numerous companies, corporations, and technical research divisions are very interested in the development of prefabricated houses. Numerous experiments, through technical research, have been and are being carried on. These experiments have been carried on during the past two decades. Several different processes have been tried and rejected without one being a lasting success. Although the Government has approved the type of prefabricated construction used for CCC housing facilities, this type has not been adapted to commercial structures. Experiments are being carried on to learn of this certain type of construction is marketable.

The general trend of prefabricated houses is toward houses built of panelized plywood. It was also found that prefabricated houses are adaptable to all climates.

These houses are more up-to-date than the dwellings ordinarily built, in that they are insulated throughout, air-conditioned, etc.

Conclusions.
In the near future the construction of homes will be revolutionized. Homes will be built of plywood, that is, the exterior and interior walls. Houses will be prefabricated, thus saving materials, lowering cost, saving time in construction, etc. Homes will be panelized prefabricated at a central mill
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