Chapter

Perspective Chapter: Prefabricated Single-Family House of Reinforced Concrete on Two Levels Prepared at the Foot of the Work and Built in a Short Time

Guillermo Yorel Noriega Aquise

Abstract

A technical design of a prefabricated single-family house of reinforced concrete on two levels is developed, to serve and assist populations in need of housing and can also be used for populations in post-emergency circumstances, due to telluric causes, landslides, floods, and others, since it is required to replace destroyed houses in a short time. It exposes a production process of precast reinforced concrete elements, to be produced in the same place of the work, with a minimum of equipment and tools that exist in a small city. It is intended to establish a low-cost construction system with precast reinforced concrete elements, which will become a technological alternative to the traditional confined masonry construction. It presents six types of two-level houses. Likewise, it exposes the building process, the costs, and assembly of the building with prefabricated elements. The basic criterion is to manufacture the elements that do not exceed the capacity of the size of the manufacturing, transport, and assembly equipment. A simple process for assembly is examined, the lowest cost is determined, in terms of direct costs, and an analysis per square meter of building will be established.

Keywords: prefabricated houses, house costs, prefabricated elements, construction system, prefabricated construction

1. Introduction

The department of Arequipa is located on the southwestern slope of the Andes of Peru, presenting a desert coastline influenced mainly by the atmospheric systems of the Coast that favor the presence of hill formations in this area. To the east, steep valleys are formed in the direction of the headwaters of the rivers, canyons, and volcanoes. The city of Arequipa, capital of the department, is located at 2326 masl. According to Warren Thornthwaite's climate classification, it presents a type of climate E(d) B′, arid, temperate, and with a deficiency of humidity in all seasons of the year, it registers maximum temperatures from 22–23°C and a minimum temperature of 11°C in summer and 7°C in winter, with a total of 70 mm of rain per year, February being the rainiest month with 28 mm [1]. However, weather stations near the mountain range record cooler temperatures [2].

Arequipa is the second largest city in Peru, it is located on the Chili River strip and in the shadow of the Misti volcano. In the second half of the twentieth century, the city underwent an accelerated urbanization process of horizontal growth, converting cultivated areas into peripheries occupied by human settlements. This expansion has lowered the population density, giving rise to areas that lack basic services [3].

-Arequipa increased its urban area by 208 km^2, in 1984 it had 67.8 km^2 and in 2020 it occupied 275.8 km^2. The green areas were reduced, especially in the districts of the northern cone, this growth is surprising and presents an unknown, regarding the quality of life in the newly inhabited areas, it is unknown if they have water, sewage, and electricity services. The total population of the city of Arequipa is 1,009,132 inhabitants, with 301,570 homes [4].

In this scenario, there is a need to have family homes in the city since there is an insufficient amount in response to population growth. The need is critical and prevailing in certain geographical spaces where telluric and catastrophic events occurred that significantly affected family homes, which in most cases were destroyed and, when assisted in post-emergency situations, are unable to replace the demolished homes, as well It happens in cases like Ica [5] in the Colca, Ichupampa [6], among others.

The construction processes used in Arequipa for the construction and reconstruction of houses are by the Confined Masonry procedure. This procedure has very high costs and demands more time, which implies that the construction processes are long and costly. Under this approach, the need for housing is not met, so there will always be a need for housing or an unsatisfied demand.

Faced with this need, it seeks to establish an alternative for the construction of single-family homes with prefabricated concrete elements established at the foot of the work with tools and equipment that cities have, with techniques and procedures that are easy to assimilate and that can be available to a population. in need of building a house. With this the periods and construction costs are shortened, and this will allow for satisfying the need for housing.

The process of building a house with prefabricated elements is more efficient than the process of building with confined masonry. In this sense, we are going to present in detail the construction process of a single-family house with two levels of precast concrete elements, it is sought that the processes are simple and easy to assimilate. The design is simple, and the lowest costs and easy construction are sought. The complexity of design and building processes is not considered in the following presentation.

2. Frame of reference

2.1 The traditional confined masonry building

Confined masonry is a system that is traditionally used in almost all of Latin America. Confined masonry is defined as that which is entirely bordered by reinforced concrete elements (except for the foundation, which can be made of cyclopean concrete and in other cases reinforced concrete), emptied after the masonry wall has been built and with a distance between columns that does not exceed more than 2 times the height of the floor. It is important to follow the indicated construction sequence so that the confines adhere to the masonry and form a set that acts in an integral manner [7].

Confined masonry is the construction technique used for the construction of a house and fired clay bricks, tie columns, screed beams, etc. are used. Confined masonry is the set or construction system formed by a brick wall, reinforced at the ends by tie columns and at the top by a concrete beam. The walls are vertical structures that separate a house from the outside or from the street. They avoid cold or heat and create different environment such as the living room, dining room, bedrooms, bathroom, and other spaces [8].

It is important that they are well built, and that they are perfectly vertical. Each brick must be settled or laid with the proper amount of mix. This mixture is called mortar, a combination of cement, coarse sand and water. A well-constructed wall is important because it can provide security and reduce finishing cost. There are two types of walls: load-bearing and non-bearing. The load-bearing wall receives the weight of the structure or is where the concrete joist rests and transmits it to the foundation. It is recognized because it is perpendicular to the joists [8].

The non-bearing wall, also known as "partition". It is the wall that does not receive any vertical weight, or that is not supported by the joist. It is always parallel to the joists, which are the concrete elements in the ceiling. It is normally suggested that load-bearing walls be wider than non-load-bearing ones, that first-story walls be wider than second-story walls, or that those on the first floor are of one type of brick and those on the second of another [8].

The government of Peru, through the National Training Service for the Construction Industry (SENCICO), develops technical training courses for masonry. It is a 447-hour face-to-face course that imparts training knowledge for a bricklayer. The Mason is the qualified operational worker who performs masonry work, such as the construction of walls, concrete floors, lining with mortar, ceramics, and porcelain; as well as the emptying of concrete elements; considering the technological knowledge related to the activities carried out, selecting with technical criteria the materials, instruments, tools and equipment necessary to carry out their work, observing the safety and quality conditions established in the plans; under the supervision of the master builder [9].

The construction processes are carried out within the framework of the national building regulations and the confined masonry construction process is considered in this regulation [10].

In Peru, knowledge of the confined masonry building process is widespread, there is technical and higher education training in confined masonry. Almost everyone uses this construction process and as a result, construction processes are achieved that require more time and cost. The need for housing persists.

In Latin America, it is one of the most widely used processes [11], and the housing requirements are similar almost throughout this geographic space.

2.2 The building proposal with precast elements of reinforced concrete

The National Association of the Precast Concrete Industry of Spain ANDECE defines a precast concrete product as a part manufactured in a fixed production plant, using concrete as the fundamental material. Said element is the result of an industrial process carried out under a defined production control system. Once manufactured and all the controls satisfied, this piece can be stored until it is delivered to the site where, together with other pieces, they will make up the final construction project [12].

The precast concrete elements are produced in a place other than their placement and are then transported, hoisted, assembled, and assembled in their final place so that they make up the complete structure. In a construction industrialization process, it is known as prefabrication. Term that refers to the production (on the construction site or outside of it) of the component elements of a structure, which will later be transported, hoisted, and assembled in their final place; so that they make up the complete structure [13, 14].

In the prefabrication process, it incurs the improvement of the construction process, faster control and detection of problems is carried out and it is carried out by specialized personnel. About the prevention of occupational risks, the risks are reduced due to less exposure of workers and a much safer environment for the development of the activity [15].

The prefabrication process contributes to sustainability, it is about manufacturing prefabricated concrete elements to assemble in a housing assembly, the advantages of carrying out in full execution *"in situ"* is expressed in the reduction of lower energy consumption, less waste generation, less dust emission, less noise generation, and reduction of transportation of materials.

On expressly prefabricated structures, which are constituted totally or partially by independently emptied elements, which are later assembled to form the total structure. The design of the precast elements consists of defining their configuration based on resistance criteria, considering factors such as: place of manufacture of the pieces, their construction procedure, weight of the elements and available lifting equipment, place of storage, curing and transport, detailing the connections between pieces [16].

The design and execution of works that consider the precast elements must be carefully planned. Determine the geometry of each part, its final location in the structure, the pipes and inserts it must contain, the connections between elements, etc. They must be clearly defined before the start of the work. It is important to consider that the manufacture of parts in series increases the efficiency of the process and allows greater control of its quality. The possibility of reusing equipment and formwork is increased [16].

The productive activities in the construction industry have had two inevitable trends of modernization; concrete quality and duration of the process are relevant factors. These two factors must be evaluated in the case of precast concrete structures. In particular, the last one, duration is a relevant factor in the cost of work, so savings of not only days but also months in some cases that can be obtained with prefabricated structures. It is this reason that can widely justify the use of precast concrete structures [17].

In quality control, precast concrete structures can far outperform the construction of cast-in-place concrete structures. The elaborate details of placing reinforcing steel in areas of possible plastic hinges in precast concrete frames can be carefully supervised in the plants that produce the precast elements [17].

There is a factor of opposition, to the use of prefabricated structures, the fear of innovation stands out, due to ignorance of the new construction processes. As in the case of areas with moderate or high seismic activity, there is a fear that precast concrete structures may behave less favorably in the face of earthquakes, as in the case of cast-in-place concrete structures. This fear should not exist, because it is possible to build prefabricated concrete structures with a seismic behavior similar to that of structures cast in place [17].

In summary, using precast concrete structures requires less labor, which is supported by the analysis of the use of labor, which implies that, by building precast concrete structures, with less execution time, they could save significant amounts of money. This is a challenge that engineering must face as part of the important changes in today's economy [17].

Our position is to look for the simplest possible outlines that allow us to reduce costs and the processes are short, in such a way that the proposed knowledge is easily assimilated by the population and technical personnel. Our proposal does not consider complex and high-cost designs, our proposal states that the diffusion will be massive.

3. Methodology

The comparison process is still an essential technique to find answers to problems of natural and social knowledge. The differences that exist between comparison as a way of thinking and as a scientific procedure are important. The first compares simple operations; the second compares complex operations. The difference lies not in the complexity of the logical structure of the comparisons, it does not present significant contrasts in science and everyday life, but in the selection and definition of the objects and properties that are compared, as well as in the care and systematicity of the production procedures and analysis of the data from which the comparisons are made [18].

The comparative method consists of empirical generalization and hypothesis verification. Among the advantages offered by the comparative method are the understanding of unknown things from the known, the possibility of explaining and interpreting them, outlining new knowledge, highlighting the peculiarities of known phenomena, systematizing information, and distinguishing differences with similar phenomena or cases [19].

The comparative method is inherent to any scientific procedure, that is, it allows us to compare the results obtained after analyzing certain variables and observing the indicators. This supposes that whenever it is compared following scientific procedures. It will be possible to compare; in which aspects they are comparable and follow the analysis strategy to reach some conclusions. No type of unconscious comparison is understood, which is not premeditated, rather it is based on established objectives [20].

For the comparison process, on the one hand, there are single-family homes designed and built with precast elements of reinforced concrete, and on the other hand, there is a design and construction of confined masonry. To carry out a comparative analysis, the factors and analysis variables have been established in both cases in such a way that the indicators and response variables can be compared objectively.

The methodological design allows us to express the procedures to respond to the approaches and achieve the objective of the Study and thus respond coherently to the guiding principles, in the search for answers that respond to the existing need.

Architectural and structural designs and construction processes are analyzed according to the approaches and the specified and delimited premises. To define the costs, the budget, and the times required for the construction of basic single-family homes to define a technical proposal that allows serving populations in need of housing in various areas of the cities and situations of post-emergency. The results analysis should achieve:

- Design construction processes for the construction of a basic dwelling.
- Establish the lowest cost of a housing construction system.

4. Results

4.1 Design and development of basic housing

Before the design of the houses, an exploratory and interpretation action was carried out on the type of houses that have been built in the last 20 years in the north of the city of Arequipa, the observation and a response it was obtained that the types of houses respond to an immediate need, that is to say, an inhabitant said that he wants as a home, an environment that houses him must have at least four walls and a roof, which must cover all the members of his family. This expression is to interpret the response of the geometry of the houses, and they are what are called constructions of the irregular box or cube type and are built with confined masonry. As their economy grows, they add irregular cubes until they form a large set of environments that allow them to develop their lives. When the economy of these families grows, they develop a more detailed and complex housing design.

The design of the houses is simple, based on the minimum necessary space, this is how the common areas that are used in the building are reproduced construction of houses and with the minimum possible space and in the same logic of the geometry of the house. With all this, the basic design criteria are established.

The design of the houses allows us to carry out a greater analysis with the use of the comparative method, with the purpose of making observations in greater detail of the proposed variables and indicators. Architectural and structural designs and construction processes are analyzed. To define the costs, and the budget that the construction of the houses demands.

The unit of study is the infrastructure of the domestic single-family home. According to the RNE, it is established that the plot of land where the house will be built is of Type 3, which gives a coverage of 160 m^2 of surface. The designs made are smaller than the assigned area and both the first and second levels are built in this area.

To carry out an analysis and achieve a greater response from the comparative method, the dominant design principle is that the useful surface of the environments of the designs are equal, that is, the useful areas of a bedroom, are the same in both types of design (prefabricated and confined masonry), as well as in all the components of the house. The outstanding and visual difference is in the thickness of the walls, in the prefabricated house it is 0.12 m and in the houses with confined masonry it is 0.15 m, and structurally larger columns and beams are added, which responds to the structural analysis. The total area occupied by a prefabricated house is less than a house with confined masonry.

4.2 Two-story prefabricated single-family home (VUF2)

Six types of single-family housing of varied dimensions of length and width are considered, whose product expressed in the surface of a level is 38.67 m^2, 54.10 m^2, 59.97 m^2, 68.58 m^2, 77.85 m^2, and 89.72 m^2 and on this same area it is built. The second level resulting in twice this built-up area (**Table 1**).

The types of houses are shown in **Figures 1–6**.

4.3 Basic single-family dwelling-confined masonry (VAC2)

Six types of single-family basic housing built by confined masonry of various dimensions of length and width are considered, whose representative product in the constructed area on one level are 39.99 m^2, 55.90 m^2, 61.60 m^2, 70.59 m^2, 80.41 m^2, 92.02 m^2, and on this same area is built on the second level, as a result it is twice this built area.

Basic Housing	Length	Width	Levels	Area	Code
Prefabricate Single Family House2-01	8.48 m	4.56 m	2	77.34 m^2	VUF2-01
Prefabricate Single Family House2-02	8.48 m	6.38 m	2	108.20 m^2	VUF2-02
Prefabricate Single Family House2-03	9.40 m	6.38 m	2	119.94 m^2	VUF2-03
Prefabricate Single Family House2-04	8.93 m	7.68 m	2	137.16 m^2	VUF2-04
Prefabricate Single Family House2-05	9.18 m	8.48 m	2	155.69 m^2	VUF2-05
prefabricate Single Family House2-06	10.58 m	8.48 m	2	179.44 m^2	VUF2-06

Table 1.
Areas and codes for two-story prefabricated single-family housing (VUF2).

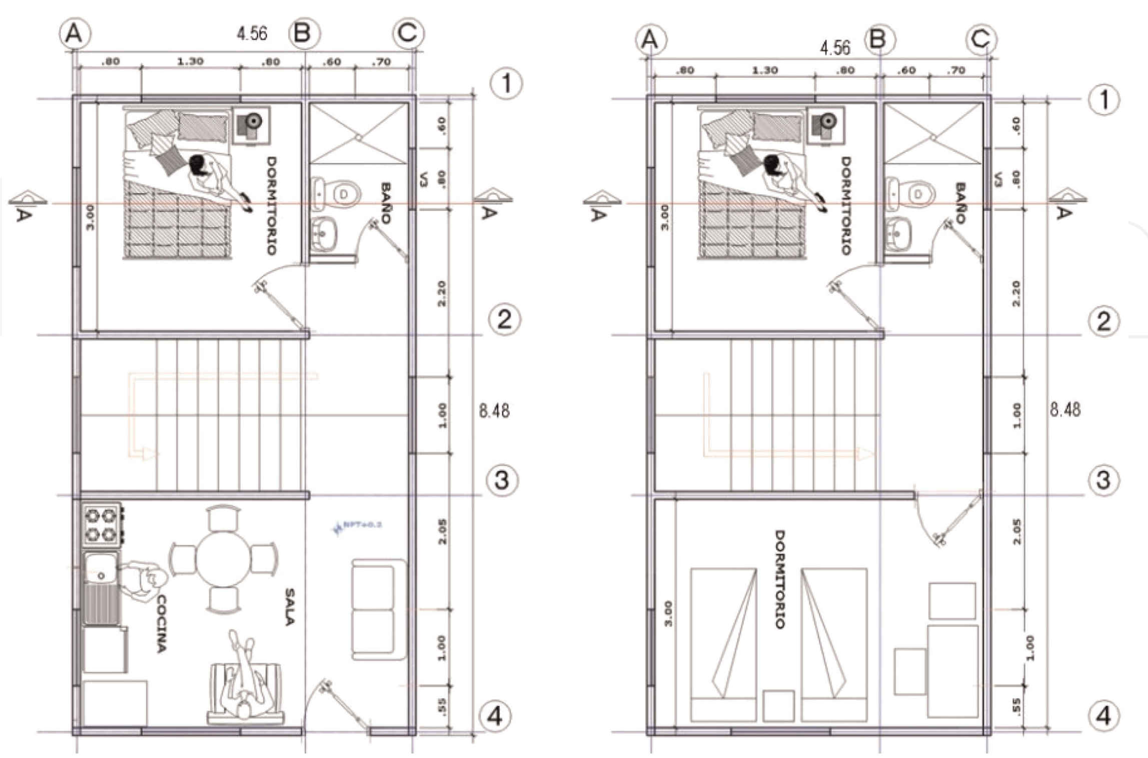

Figure 1.
Plan view VUF2-01 first level and second level.

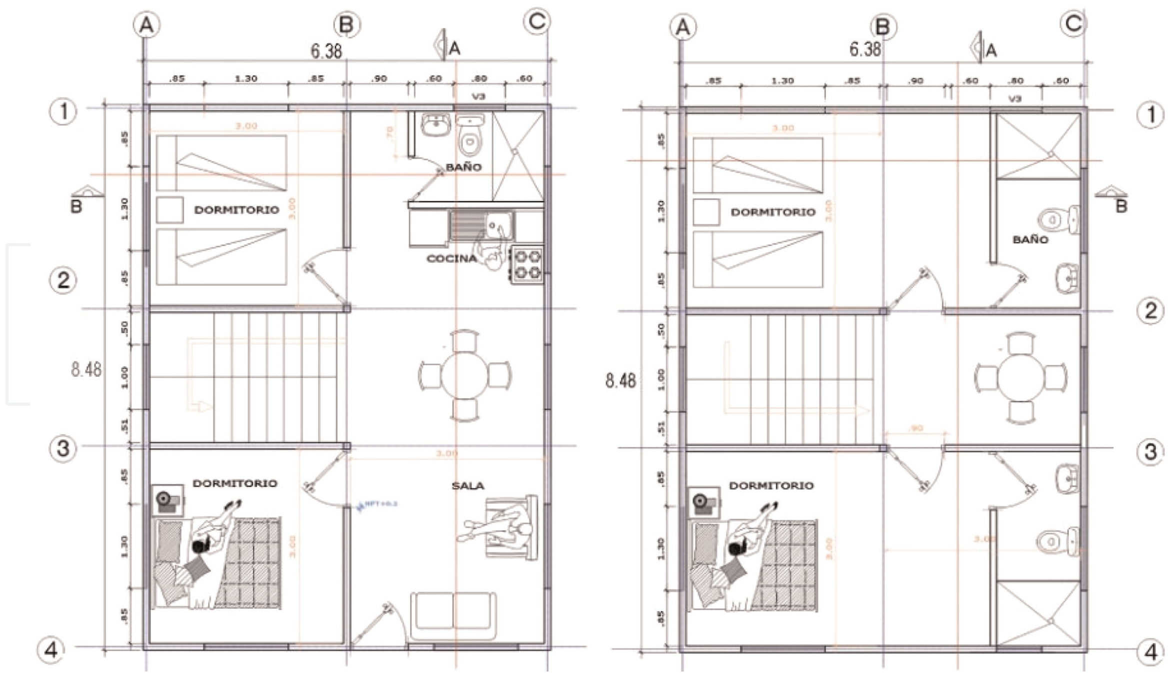

Figure 2.
First level and second level plan view VUF2-02.

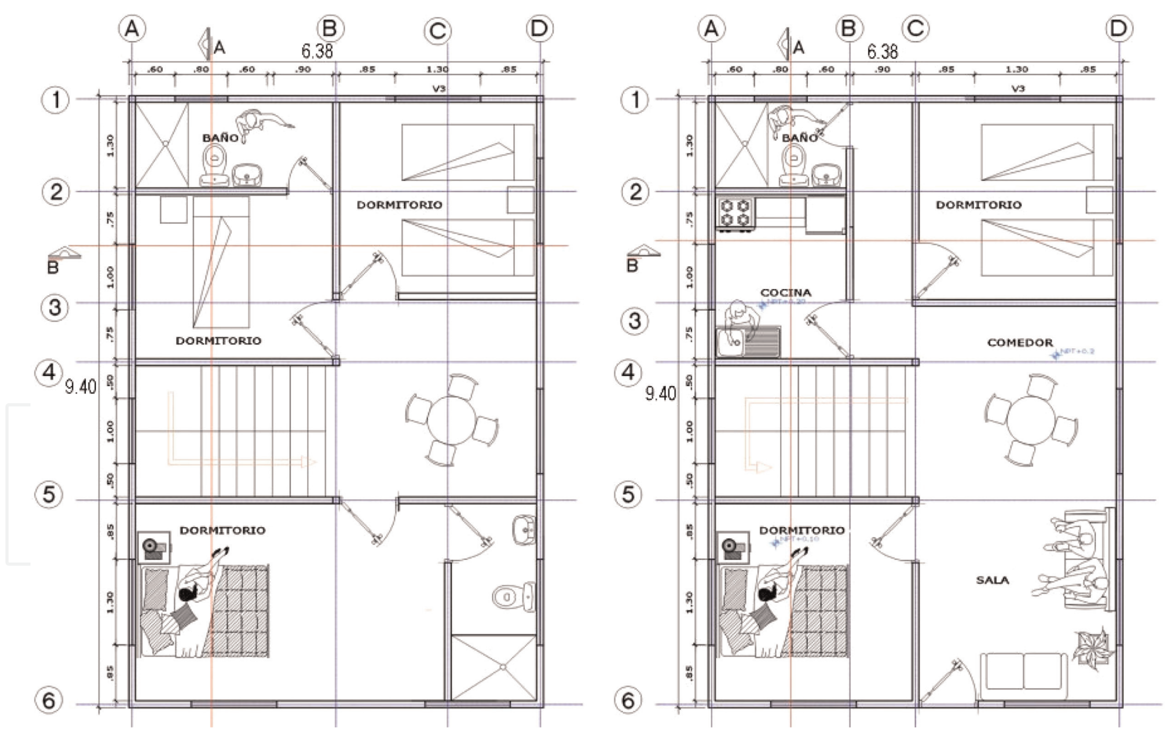

Figure 3.
First level plan view and second level VUF2-03.

The designs of houses with confined masonry are similar to the design of houses with prefabricated elements, the variation is in the width of the wall and the details that are followed in a building by confined masonry (**Table 2**).

Diagrams of plans for the construction of a house with confined masonry are presented, the design is a complex system that requires further analysis and for the

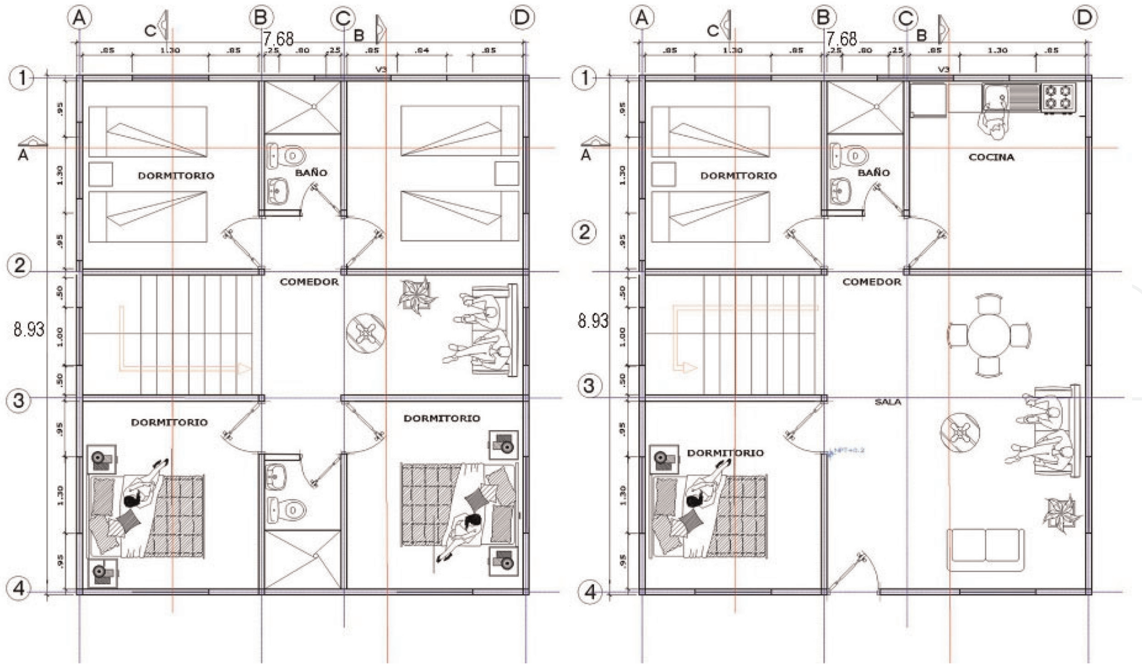

Figure 4.
First level plan view and second level VUF2-04.

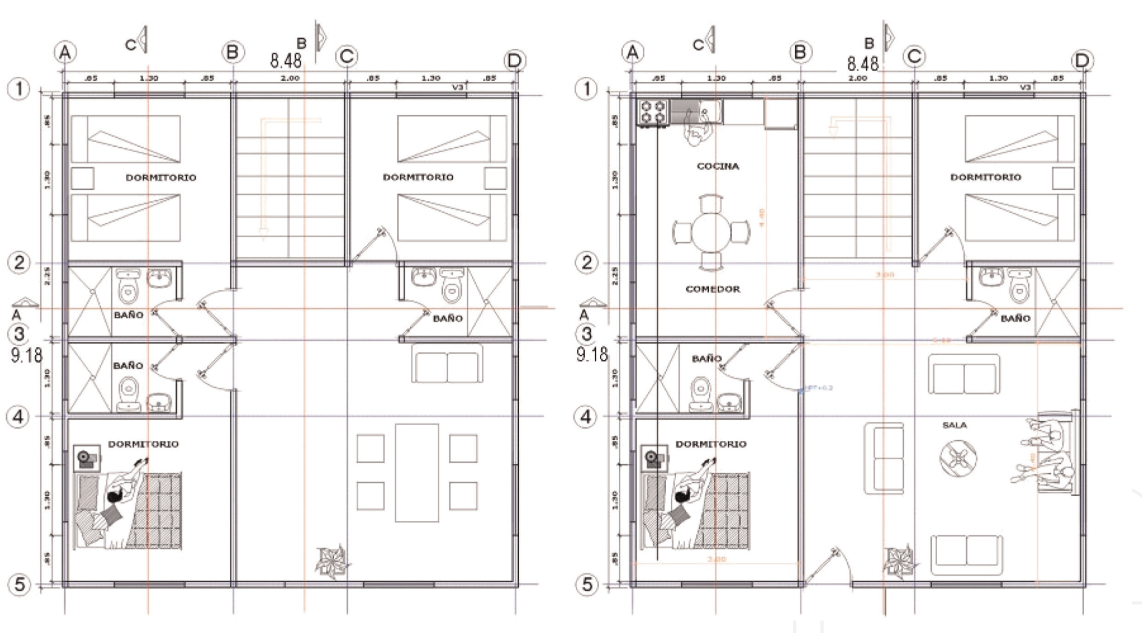

Figure 5.
First level plan view and second level VUF2-05.

construction, more time is required for its construction, as well as a greater amount of materials, and which gives a answer that the building processes by confined masonry have a higher cost than the buildings with prefabricated elements (**Figures 7–11**).

4.4 Comparison of surfaces of environments of VUF2 and VAC2

To carry out a correct application of the comparison methodology, the important factor is considered the principle of similarity–equivalence as well as the surface of the

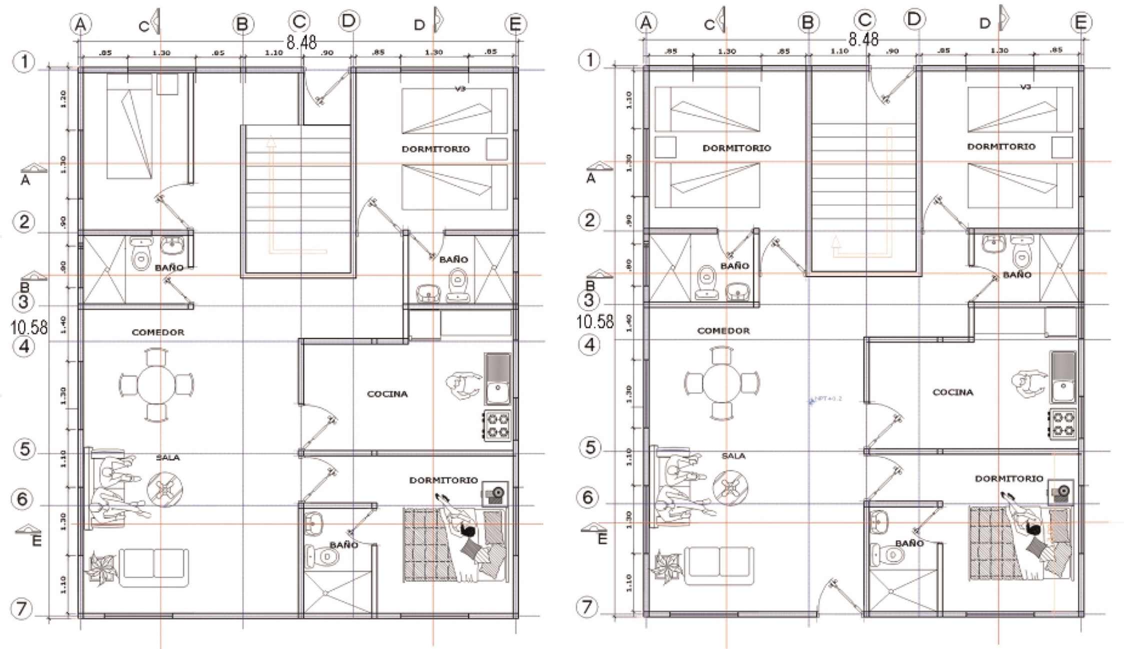

Figure 6.
First level plan view and second level VUF2-06.

Basic housing	Length	Width	Levels	Area	Code
Housing Confined Masonry 2-01	8.60 m	4.65 m	2	79.98 m^2	VAC2-01
Housing Confined Masonry 2-02	8.60 m	6.50 m	2	111.80 m^2	VAC2-02
Housing Confined Masonry 2-03	9.55 m	6.45 m	2	123.20 m^2	VAC2-03
Housing Confined Masonry 2-04	9.05 m	7.80 m	2	141.18 m^2	VAC2-04
Housing Confined Masonry 2-05	9.35 m	8.60 m	2	160.82 m^2	VAC2-05
Housing Confined Masonry 2-06	10.70 m	8.60 m	2	184.04 m^2	VAC2-06

Table 2.
Areas and codes of single-family housing confined masonry of two levels (VAC2).

environments both of VUF2 and equal to VAC2. This implies that the areas of occupation and use of the environments of the dwellings are the same in the corresponding type of dwelling. The areas occupied by the passageways and stands are also the same.

On the other hand, the surface occupied by the walls are different, this is due to the fact that the wall occupied by prefabricated elements is less than the spaces occupied by the building by confined masonry and the difference must lie in the width of the wall of prefabricated houses is 0.12 m and that of confined masonry is 0.15 m (**Tables 3** and **4**).

Regarding the percentage ratio of the area occupied by rooms in relation to the total built surface, the areas occupied by rooms are greater in homes with precast concrete elements than those built with confined masonry. On the other hand, the surface occupied by masonry walls is greater than the percentage of the surface occupied by houses built with confined masonry (**Tables 5** and **6**).

DOI: http://dx.doi.org/10.5772/intechopen.113351

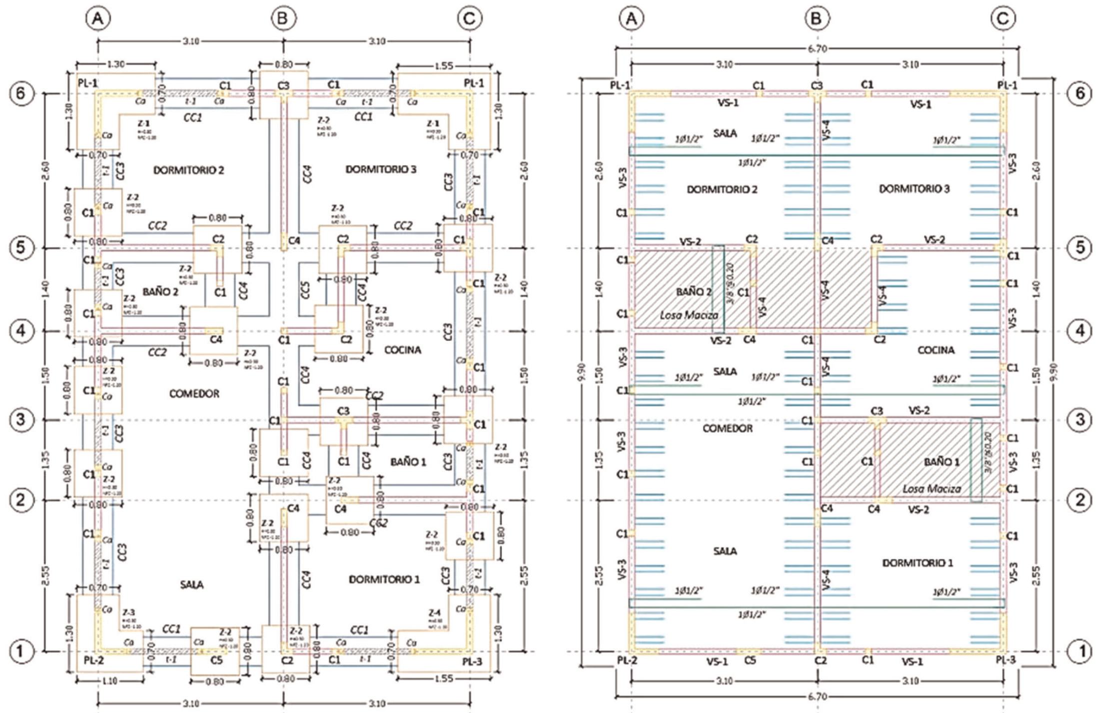

Figure 7.
Plan of the foundation and lightening of a VAC.

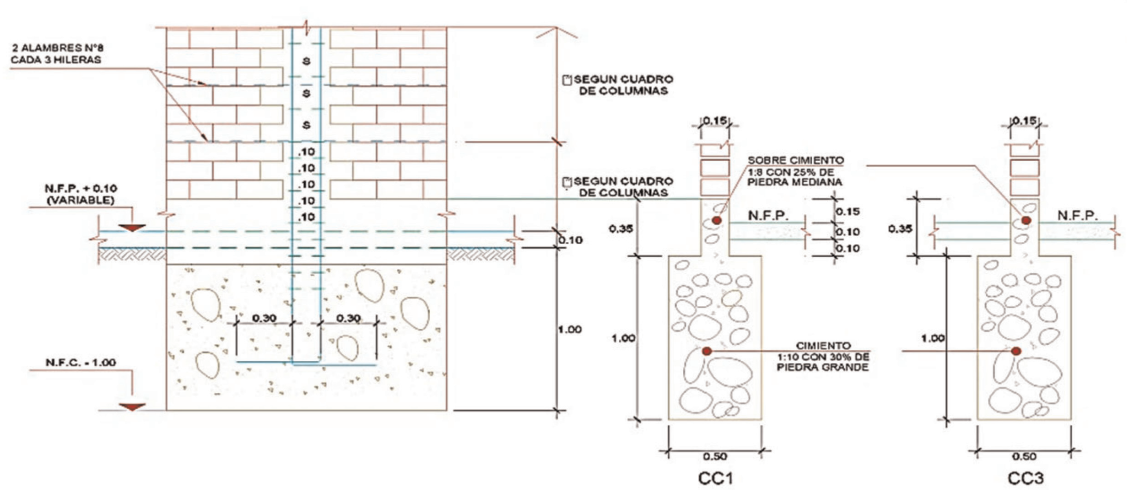

Figure 8.
View of column and continuous foundation in VAC confined masonry.

4.5 Building process of a house with prefabricated elements VUF2

Usually, the manufacture of precast concrete elements is normally carried out in fixed production plants, which are equipped with the necessary machinery and specialized personnel that comply with the standards and projected design. In a production plant, prefabricated elements can be produced to make homes with complex designs and works of art a reality with specialized personnel. Of all this, there is a lot of experience.

Our proposal goes to the extreme of what exists, and it is intended to carry out a process to elaborate prefabricated elements of reinforced concrete at the foot of the

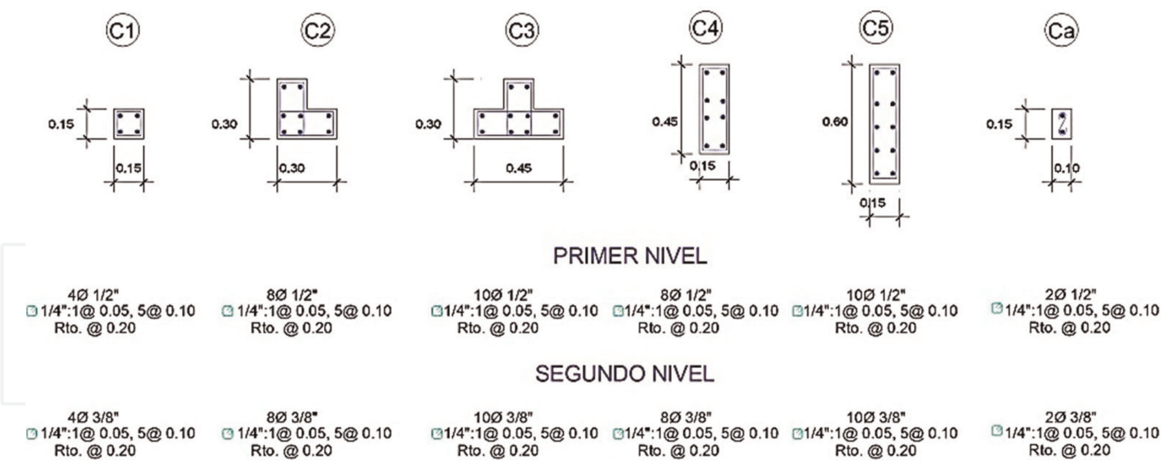

Figure 9.
Column section and detail of the necessary iron in VAC confined masonry.

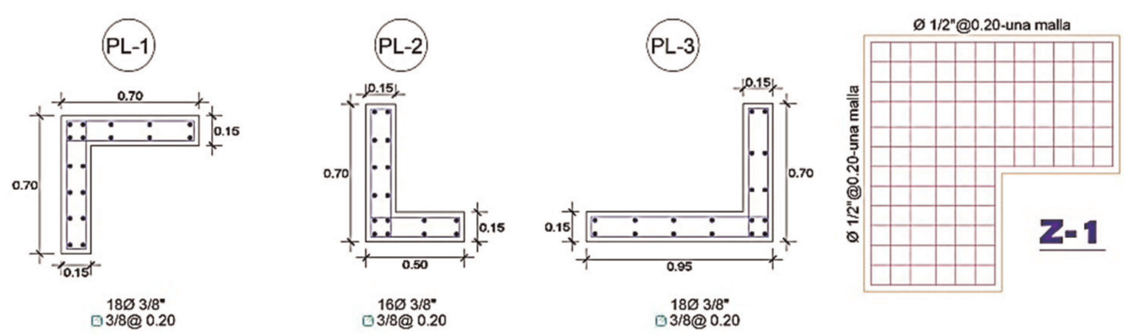

Figure 10.
Section of plates, footing, and detail of the necessary iron in VAC confined masonry.

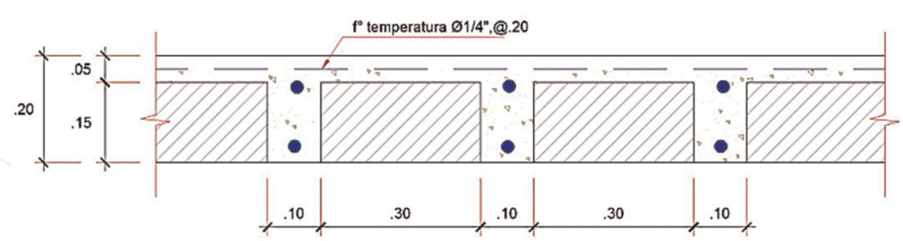

Figure 11.
Lightening section of the first level in VAC confined masonry.

Rooms in m^2	VUF2-01	VUF2-02	VUF2-03	VUF2-04	VUF2-05	VUF2-06
Kitchen, dining room, living room, bedroom, SH	49.00	80.76	88.00	98.32	113.49	123.23
Passageways and bleachers	20.06	14.70	18.30	18.50	20.40	32.08
Walls	8.28	12.74	13.64	20.34	21.80	24.13
Total area	77.34	108.20	119.94	137.16	155.69	179.44

Table 3.
Detail of the rooms on two levels by surface area in square meters (VUF2).

Rooms in m^2	VAC2-01	VAC2-02	VAC2-03	VAC2-04	VAC2-05	VAC2-06
Kitchen, dining room, living room, bedroom, SH.	49.00	80.76	88.00	98.32	113.49	123.23
Passageways and bleachers	20.06	14.70	18.30	18.50	20.40	32.08
Walls	10.92	16.34	16.90	24.36	26.93	28.73
Total area	79.98	111.80	123.20	141.18	160.82	184.04

Table 4.
Detail of the rooms on two levels by surface area in square meters (VAC2).

Rooms in percentage	VUF2-01 (%)	VUF2-02 (%)	VUF2-03 (%)	VUF2-04 (%)	VUF2-05 (%)	VUF2-06 (%)
Kitchen, dining room, living room, bedroom, SH.	63.36	74.64	73.37	71.68	72.89	68.67
Passageways and bleachers	25.94	13.59	15.26	13.49	13.10	17.88
walls	10.70	11.78	11.38	14.83	14.00	13.45
Total area	100.00	100.00	100.00	100.00	100.00	100.00

Table 5.
Detail of the rooms on two levels by occupancy percentage (VUF2).

Rooms in percentage	VAC2-01 (%)	VAC2-02 (%)	VAC2-03 (%)	VAC2-04 (%)	VAC2-05 (%)	VAC2-06 (%)
Kitchen, dining room, living room, bedroom, SH	61.27	72.24	71.43	69.64	70.57	66.96
Passageways and bleachers	25.08	13.15	14.85	13.10	12.68	17.43
Walls	13.65	14.62	13.71	17.25	16.75	15.61
Total area	100.00	100.00	100.00	100.00	100.00	100.00

Table 6.
Detail of the rooms on two levels by occupancy percentage. (VAC2).

work with the equipment that exists in common cities. For which the equipment to be used must have the property of self-mobilizing to a place with minimum conditions and that they are in the place where the prefabricated houses are assembled.

Prefabricated concrete houses are structures that are built using precast concrete panels, the panels are made on the building site and then it is where they are assembled to form the structure of the house. The characteristics that must be fulfilled are:

- The prefabricated panels are made using molds and formwork, which can be of different sizes and shapes, and are framed in the project design. The panels make up the wall, ceiling, and floor. Steel reinforcement is installed between the panels as designed to provide strength and stability.

- There is greater efficiency in building a precast concrete house and they offer faster construction compared to traditional methods. The controlled elaboration of the panels allows greater precision and quality in the construction.

- It has greater resistance and durability because it is made of concrete and offers a solid and resistant structure, capable of supporting structural loads and resisting the effects of weather and time.

- It presents good thermal and acoustic insulation and helps reduce heat transfer and noise between the interior and exterior of the home.

- The combination of the various concrete elements allows for a flexible design and can be adapted to different architectural styles and individual needs.

The machines and equipment to be used are:

- Loading and hoisting devices for precast elements.

- Self-propelled concrete mixer or purchase ready-mix concrete with built-in additives.

- Independent horizontal molds are made of wood or metal or mixed.

- 10 MT self-propelled crane

- Hand tools and accessories.

Initially, the beams and foundation slab must be installed. On which the other pieces of prefabricated elements required for the construction of the prefabricated house will be installed.

To make the other prefabricated parts, the necessary molds must be available where the elements must be made to carry out mass production, considering the defined technical specifications. The molds are the fundamental part and respond directly to the results. Its design must respond to the specific requirements of the projects. However, efficiency increases when a mold or a reduced number of molds can be versatile and can produce a wide variety of precast concrete elements and allow the development of various types of works. Meeting the requirements in terms of dimensions, stability, and low deformation.

To make the various prefabricated elements of the six basic single-family homes, a 2.40 m × 12.60 m mold has been designed with a variable thickness of 0.12–0.50 m, designed from iron plate, having to have several molds, which have devices that can shape smaller pieces and variable configuration, as well as shape the doors and windows, it must also allow placing the sanitary and electrical installations, before the pouring of the concrete.

The concrete used in manufactured homes can vary depending on the specific design, and structural requirements, and the following must be considered:

- The concrete mix consists of a combination of cement, plus aggregates (such as sand and gravel), and water. The proportion of these can vary according to the requirements of strength, durability, and workability.

- The strength of the concrete is indicated on the plans, but the minimum requirement is 210 kg/cm^2.

- The strength and load capacity of the concrete is improved and steel reinforcement in the form of bars or mesh must be placed.

- Admixtures and admixtures are added to concrete to improve certain properties, which may include:

- Plasticizers, or water reducers, are used to improve the workability of concrete, allowing better fluidity and workability without significantly increasing the amount of water in the mix.

- Superplasticizers, known as high-range super water reducers, these additives have a similar effect to plasticizers but can achieve greater water reduction in the mix without sacrificing workability.

- Accelerating admixtures are used to speed up the setting and hardening process of concrete.

- Retarding admixtures act the opposite of accelerators, allowing a longer working time before the concrete begins to harden.

- Aeration admixtures allow small air bubbles to be introduced into the concrete, improving resistance to freezing and thawing and reducing the possibility of cracking due to ice expansion in cold climates. Aeration admixtures can improve the durability and strength of concrete in harsh environments.

To carry out the elaboration of precast concrete elements, the following process must be carried out:

- Define the design of the basic single-family home.

- Preparation of the elements to be prefabricated.

- Molding, placement of meshes and pipes.

- Installation of anchoring and lifting devices.

- Pouring of ready-mix concrete plus additives.

- Finishes.

- Accumulation of parts and cataloging.

Once the necessary parts have been obtained, after obtaining the due and proven resistance, we proceed to carry out the assembly (**Figures 12–19**).

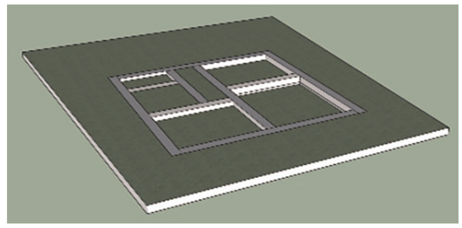

Figure 12.
Foundation beam installation.

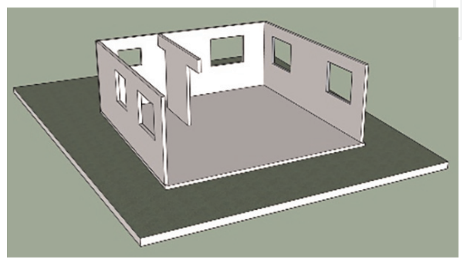

Figure 13.
Installation of foundation slab and walls.

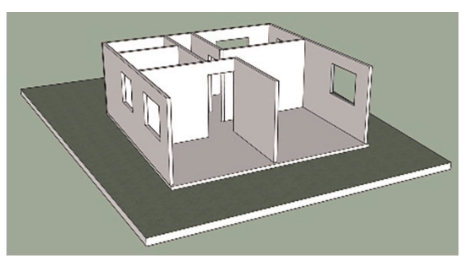

Figure 14.
Dividing and perimeter walls.

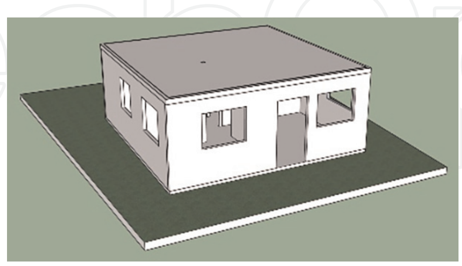

Figure 15.
First level ceiling installation.

4.6 Structure of precast elements of reinforced concrete

The structural system of precast concrete elements includes the following elements: foundation beams, and foundation slabs—floor, walls, and roof, under an approach of articulated structural panels with anchors that support the stress requests.

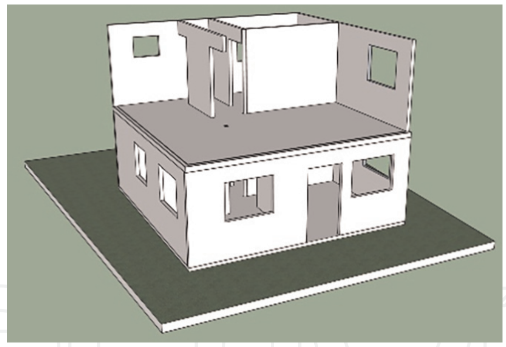

Figure 16.
Dividing walls 2nd level.

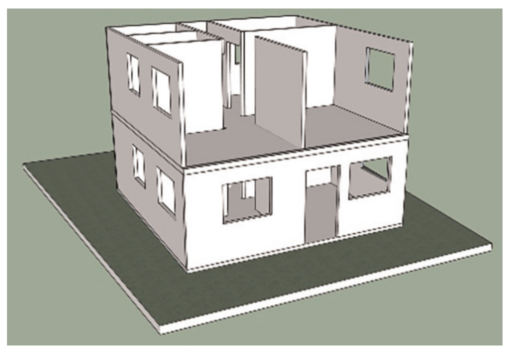

Figure 17.
Perimeter walls 2nd level.

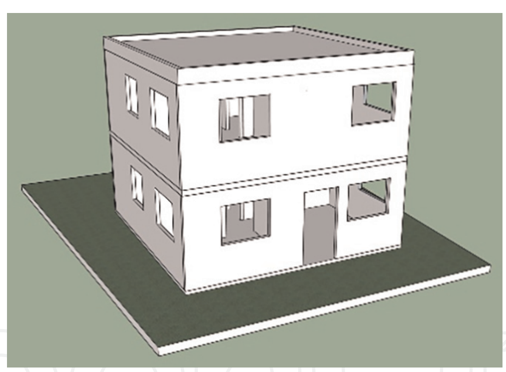

Figure 18.
2nd level ceiling installation.

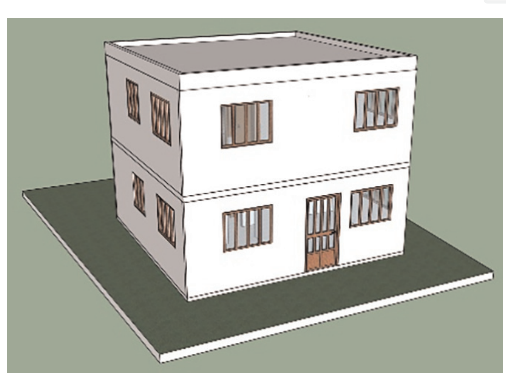

Figure 19.
VUF2 finished prefabricated.

The elements must reach a sufficient resistance for handling and assembly. They must withstand the weather and the inclemency of the place.

Each element of the reinforced concrete panels that go on the floor, the walls, and partitions must have a minimum resistance of 210 kg/cm^2 with mesh every 0.20 m in both directions of iron with a diameter of 3/8″ in diameter and on the perimeter Next to the edge there are two equidistant irons with a diameter of 1/2″ in diameter, they are also installed as reinforcements in the corners and critical places. Lifting and transport devices are installed. It is possible to use various anchoring systems if it responds to the effort requests that the prefabricated parts require.

The elements of the roof are 0.20 cm thick and have a double 3/8″ mesh and on the perimeter, there are two parallel ½″ irons in each mesh, it is also placed in the critical links.

Two panels with exposed structures are shown, the others show a similar constitution (**Figures 20** and **21**).

Rectangular finite elements have been used whose formulation obeys a thin sheet behavior which is adequate for the representation of 12 cm thick walls, establishing a

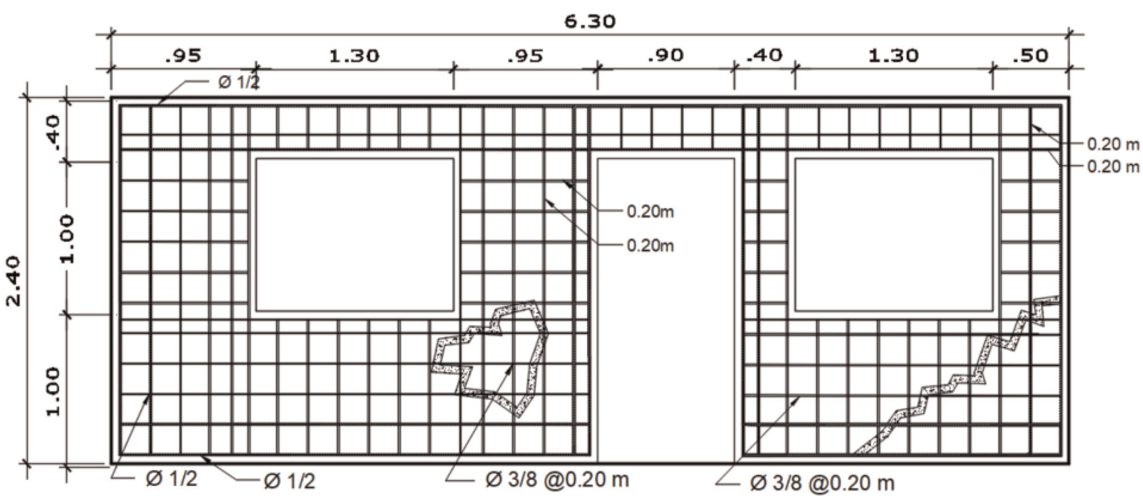

Figure 20.
Structure of a front part of the VUF2.

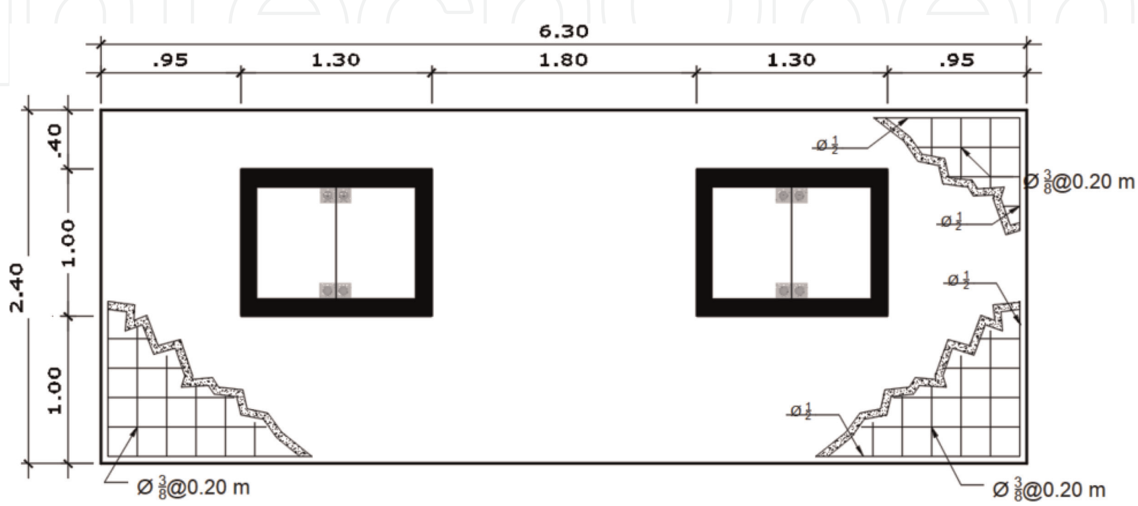

Figure 21.
Structure of a rear part of a VUF2.

consistent mesh with the compatibility of deformations in the nodes and with the appropriate level of precision. For the interpretation of the results (**Figure 22**).

There are various types of anchoring devices and connections for use in manufactured homes that may vary depending on the specific design and requirements of the structure. Some common types of anchors are presented, which are connection devices between precast panels, which are:

- Embedded bolt anchors consist of steel bolts or rods that are embedded in the concrete during the fabrication of the precast panels. These bolts protrude from the panel and are used to secure and join the panels to foundations or other structural elements.

- Anchor plates are steel plates that are attached to precast concrete and are used to provide additional fixing points. These plates often have pre-drilled holes to allow for bolt or screw connection.

- Welded connections, which can be joined by welded connections, involve the welding of additional steel elements to the concrete plates to provide a strong and rigid joint.

- The mechanical connectors are made of steel or spike connectors, to join the precast concrete plates. These connectors are inserted into holes drilled in the boards and attached by clamping or soldering.

It is important to note that the selection and design of the anchors depend on the configuration of the structure, the load forces, and the strength requirements, to guarantee a safe and reliable connection of the plates in the prefabricated houses.

A vertical anchoring system has been designed that can be used in critical places and can respond to greater demands, this model is still being tested and could be used, in our analysis it allows to give greater resistance to the designed structures of prefabricated houses of reinforced concrete. The use must respond to the structural calculation proposed by the structuralists. This unit can be additionally placed in the critical corners of the connection of the panels, which require greater demands, the internal mesh is ½″ iron placed equidistantly and parallel according to the senses. The connection of the

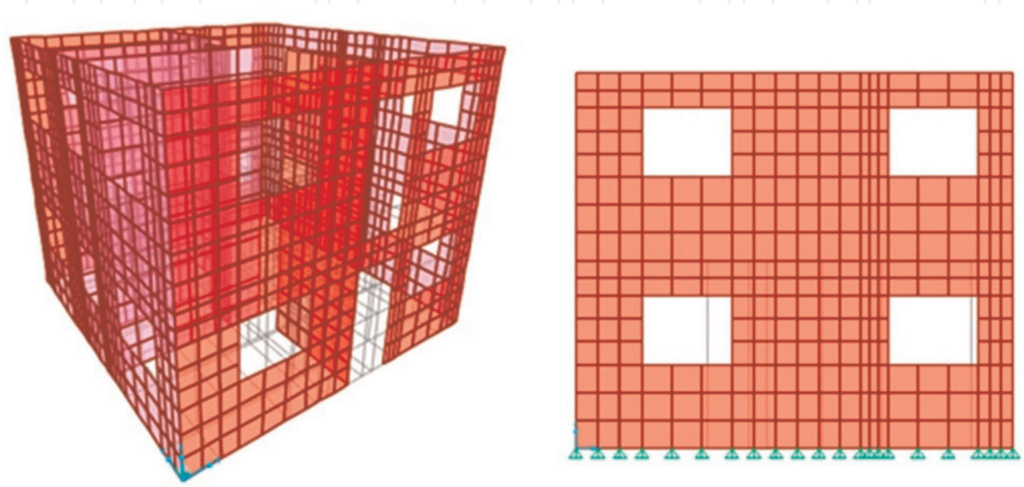

Figure 22.
Structural model of housing panels and front view structural model.

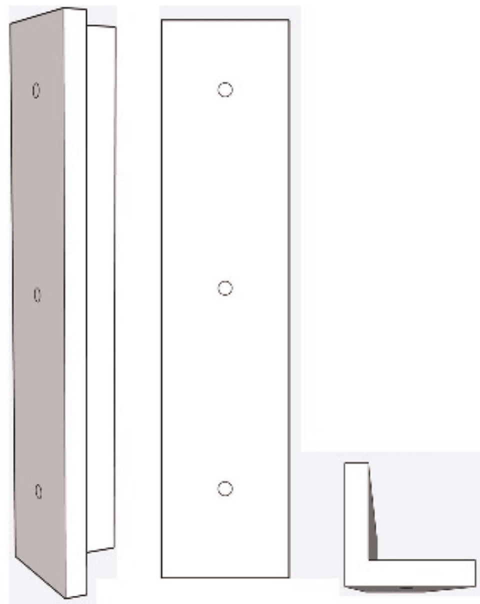

Figure 23.
Prefabricated anchoring for panels of a VUF2.

device with the panels is done with a bolt that responds to your structural requests and must necessarily be covered with elastomeric tape (**Figure 23**).

4.7 Direct costs of VUF2 and VAC2

The direct cost refers to all those expenses that are directly related to the construction of a work, it will be expressed in the amount of labor, materials, and equipment used in the execution of a work, which will be expressed in national currency and in US dollars at the exchange rate when the budget was prepared.

Six designs of houses with prefabricated elements have been carried out to explore the changes and variations that may exist in the process of building houses with prefabricated elements, in such a way that the comparative methodology allows us to know in greater detail the process of elaboration and construction of prefabricated houses.

For each type of housing designed, architectural and structural plans have been developed, from which the corresponding measurements have been made. These measurements were processed in the S10 cost and budget program.

The costs of prefabricated houses per square meter are shown, according to the type of VUF2 house. For each construction item, an analysis of unit costs was carried out, indicating the number of materials used and considering the equipment and machines necessary for its manufacture and assembly.

The cost of a two-story prefabricated house is in the range of US$ 27,976 US dollars, which corresponds to a VUF2-01, and the VUF2-06 house, which has a cost of US$ 64,218 US dollars. The lowest cost per square meter corresponds to housing VUF2-04, which is US$ 304.18 US dollars, and the highest cost per square meter corresponds to VUF2-05, which is US$ 391.25 US dollars (**Table 7**).

Six housing designs have also been made to be built with confined masonry, to explore the changes and variations that may exist and, at the same time, make a comparison with the houses built with prefabricated elements (**Table 8**).

Description	VUF2 Area's	Cost in dollars	Cost per m^2
Direct cost VUF2-01	77.34 m^2	US$ 27,976.65	US$ 361.75
Direct cost VUF2-02	108.20 m^2	US$ 33,536.08	US$ 309.93
Direct cost VUF2-03	119.94 m^2	US$ 38,992.55	US$ 325.09
Direct cost VUF2-04	137.16 m^2	US$ 41,722.74	US$ 304.18
Direct cost VUF2-05	155.69 m^2	US$ 60,914.11	US$ 391.25
Direct cost VUF2-06	179.44 m^2	US$ 64,218.57	US$ 357.89

Table 7.
Direct cost of a VUF2 in US dollars.

Description	AC2 Area's	Cost in dollars	Cost per m^2
Direct cost AC2-01	79.98 m^2	US$ 38,670.32	US$ 483.5
Direct cost AC2-02	111.80 m^2	US$ 52,046.46	US$ 465.53
Direct cost AC2-03	123.20 m^2	US$ 60,537.14	US$ 491.39
Direct cost AC2-04	141.18 m^2	US$ 59,852.36	US$ 423.94
Direct cost AC2-05	160.82 m^2	US$ 86,427.67	US$ 537.42
Direct cost AC2-06	184.04 m^2	US$ 97,712.21	US$ 530.93

Table 8.
Direct cost of a AC2 in US dollars.

The cost of a house built by confined masonry is in a range of US$ 38,670 US dollars, which corresponds to an AC2-01 and the cost of the house in AC2-06 is US$ 97,712 US dollars. The lowest cost per square meter corresponds to housing AC2-04 which is US$ 423.94 US dollars and the highest cost per square meter corresponds to AC2-05 is US$ 537.42 US dollars.

A comparison has been made between the costs of a building with precast elements of reinforced concrete and a confined masonry design. The confined masonry process is a system that is traditionally used in Peru and Latin America.

Confined masonry is defined as that which is completely bordered by elements of reinforced concrete [8]. Although the designs represent a higher cost compared to prefabricated houses, it does not imply that the confined masonry process is limited, rather it requires a lot of experience to achieve greater efficiency and reduce labor costs to their maximum expression (**Figure 24**).

The design of the prefabricated houses has been modeled by anti-seismic structural calculations with a response of equal magnitude. Once this similarity has been achieved, the measurement analysis has then been developed and processed in the S10 cost and budget program, in Microsoft Project, and SPSS.

The cost trend of the confined masonry building process is higher than the cost trend of a manufactured home. Probably, the complexity of the design and the construction process of the confined masonry affects its higher cost, while in the building with precast elements, the simplicity of the design and the construction process guide its tendency to have the lowest cost (**Figure 25**).

The dimensions used for the building surface correspond to the observations made by the inhabitants who develop their homes, these chosen surface dimensions respond

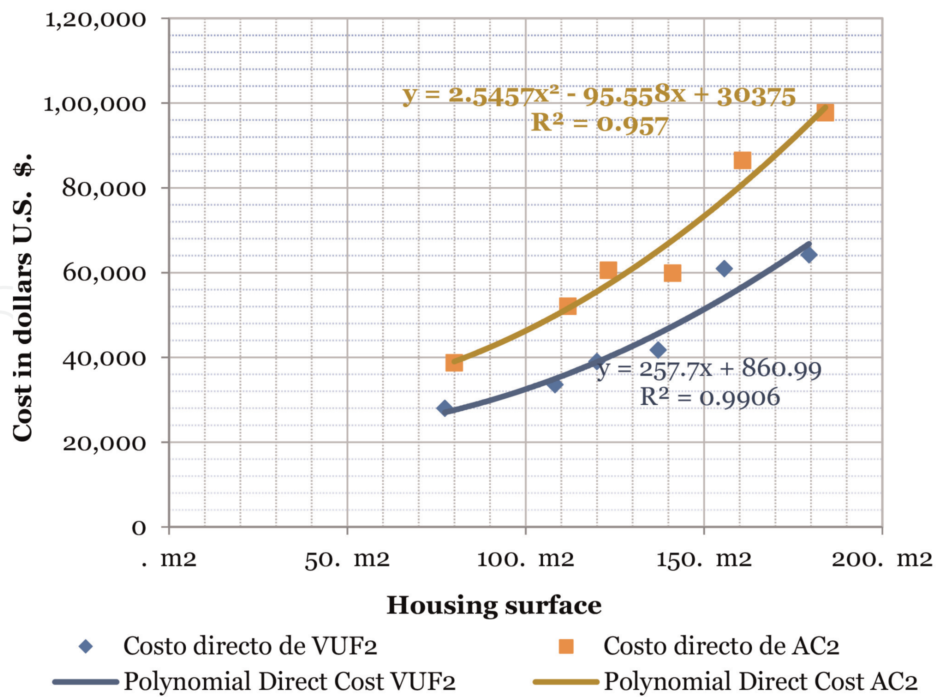

Figure 24.
Cost/area trend lines of VUF2 and AC2.

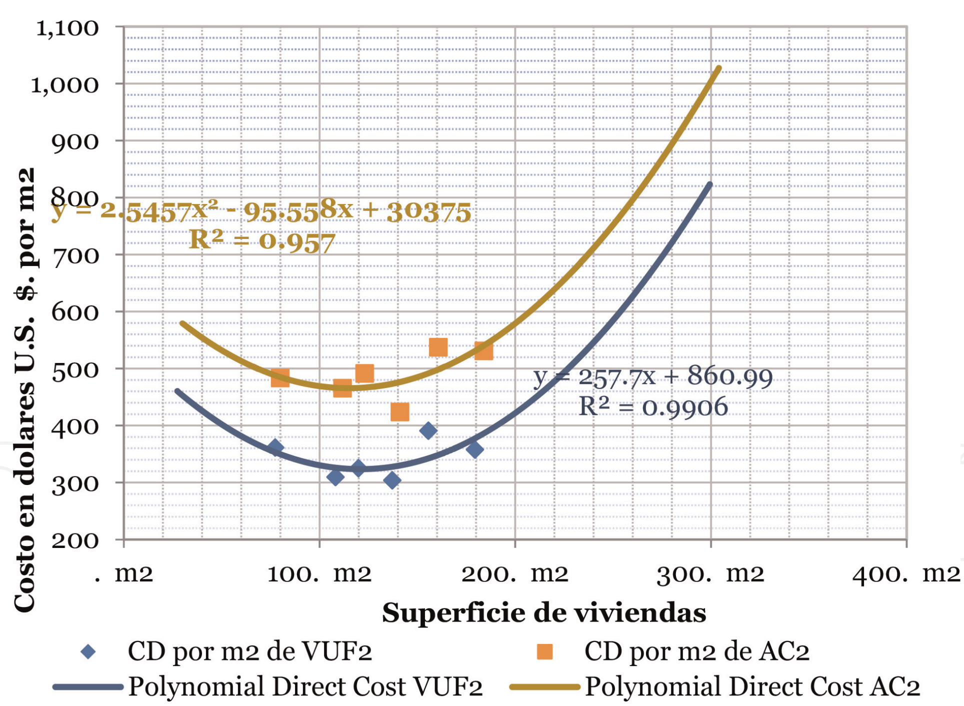

Figure 25.
Cost trend/area lines of VUF2 and AC2.

to the needs of the inhabitants. It can likely be understood that this chosen sizing represents a group of dwellings that are in the lower part of the polynomial, the higher the built-up area the prices per square meter would tend to rise, and if the prices per square meter are less than this chosen area. Costs per square meter would be higher than houses built with smaller surfaces.

DOI: http://dx.doi.org/10.5772/intechopen.113351

5. Conclusions

- Six types of basic two-story single-family homes have been designed and are following the standards and can be accessible to low-income economies. All designs are framed in a 160 m^2 lot, each type of home satisfies the needs of a simple to extended family, and depending on their economic availability, they can choose according to their requirement for environments. Designing six types of housing is related to the research method used, thus establishing the six types of housing allows us to explore the various variables and types of trends that could occur in the future in a housing establishment process. Prefabricated at a massive level. The areas of the six types of housing respond to the state in which it is located, in urban areas according to the type of housing surface that is occupied by families.

- The costs of prefabricated reinforced concrete homes are lower in cost than homes built with confined masonry. In homes with prefabricated elements, the surface of the land is used more efficiently, and the space is occupied by the walls on the confined masonry surface. The analysis of six types of homes allows us to understand the trend in the construction process of prefabricated homes compared to homes built with confined masonry, which confirms that using the comparative research method allows us to understand the trend in the cost of construction to a greater extent. The works as the time to be used in the construction processes.

- The elaboration and construction of prefabricated housing on the construction site is feasible, and it also allows assembly with the minimum equipment that exists in a city, both for the elaboration and for the assembly of the prefabricated housing. The equipment used is minimal and can be available in cities and the operation of this equipment is simple and can be maneuverable in small areas of land, which allows the work to be carried out in less time.

- The lowest cost of a prefabricated housing manufacturing and assembly system. The direct cost has been achieved in VUF2-04 for $304.18 US dollars per square meter and indirect costs of $27,976.65 US dollars for a constructed area of 77.34 m^2 that corresponds to a land area of 38.67 m^2.

- The cost trend responds to a square polynomial and the costs of a building using confined masonry turn out to be higher than the costs of a building process using prefabricated concrete elements. There is a proportionality ratio between the direct costs of the construction processes since when analyzed per unit of built surface the trend equation and their relationship values are similar.

- There is a personal conviction to develop and make available technology, techniques, and processes that can be used by the various entities that assist the population in need of housing. With which families can have access to basic housing or solve the effects of a post-emergency situation. We hope to be able to disseminate the knowledge achieved in the future, after putting it into practice.

Conflict of interest

"The authors declare no conflict of interest."

Author details

Guillermo Yorel Noriega Aquise[1,2]

1 Catholic University of Santa María Arequipa, Peru

2 Magister Construction Management, Peru

*Address all correspondence to: gnoriega@ucsm.edu.pe; gmonoriegae@gmail.com

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