Chapter

Low-Cost Single-Family House through The Use of Precast Reinforced Concrete Elements

Guillermo Yorel Noriega Aquise

Abstract

A technical design is developed to attend and assist populations in need of single-family housing and for populations in post-emergency situations. It exposes a production process of precast reinforced concrete elements, to be produced in a small production plant or at the site, with a minimum of equipment and tools. It is intended to establish a low-cost single-family house construction system with prefabricated reinforced concrete elements, which will become a technological alternative to traditional confined masonry construction. It presents a production line of six types of houses. For the comparison, a methodological process is followed, the comparison is made between the process of building houses with precast concrete elements and with the building process by confined masonry, the traditional process most used in Peru. The dominant principle of comparison is the equality of the useful surface of the rooms. The outstanding and visual difference is in the thickness of the walls, in the prefabricated house it is 0.10 meters and in the houses with confined masonry it is 0.15 m. The costs, production times and assembly, of the building with prefabricated elements, is low, compared to the building process by confined masonry. An in-line production process is established, of prefabricated elements with minimal equipment. The basic criterion is to manufacture that does not exceed the capacity of the size of the manufacturing, transport and assembly equipment. A simple process for the assembly was examined, a minimum period of construction of a prefabricated house of 2 hours was determined at any time of the year. The lowest cost, the direct cost has been achieved in VUF 04 at $ 264.50 US dollars per square meter and in total costs of $ 374.54 US dollars per square meter.

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

1. Introduction

A technological alternative is sought that responds to the need for the construction of a low-cost single-family basic house and is implemented agilely in the short term.

When analyzing the housing situation in Peru, common problems are found, as in all Latin American countries. There is a very large housing deficit both because of the famine and because of the physical deficiencies of the existing houses. According to different estimates, this deficit is equivalent to just over half of all existing houses. The severity of the housing problem varies greatly within the region and within each country and even within the same city [1].

Nine out of 10 houses in Latin America and the Caribbean are of low quality. "*Currently, more than 75% of the inhabitants of Latin America and the Caribbean reside in urban areas. The challenge is how to eradicate the poverty cords and the deterioration that this generates and that does not allow good quality of housing in our hemisphere*," Luis Alberto Moreno, president of the BID, explained to EL PAÍS. In the last 20 years Brazil, Colombia, Peru, Chile, Paraguay and Argentina, delivered more than six million housing units to low-income populations. This policy has not prevented the emergence of low-quality housing clusters on the outskirts of cities, far from work centers [2].

Peru is the third country in Latin America with the highest housing deficit, according to the report of the Ministry of Housing, Construction and Sanitation, of the Peruvian government. They state that there is a deficit of 1800,000 houses, among families that do not have a house or live in a precarious house. Peru ranks third in Latin America as the country with the highest housing deficit. After Nicaragua and Bolivia [2].

The housing deficit in the face of a low supply leads to an increase in the price of houses. According to the Peruvian Chamber of Construction (CAPECO), in recent years there has been an increase in the average price of departments in Lima and Callao. The price per square meter (m^2) during 2015 was 4,623 soles and increased by 5.5% for 2016; by zone, the largest hike was presented in Lima Modern that went from 4,794 soles per m^2 in 2015 to 5,187 soles per m^2 in 2016. The high prices make it unattainable to obtain a house for everyone. Additionally, the high informality in construction in low-income districts increases the housing deficit [3].

The need for housing is critical in certain geographic spaces where telluric and catastrophic events occurred. Thus, the mayor of the Provincial Municipality of Ica-Peru, in August 2017 pronounced on the insufficient reconstruction of Pisco and states that after 10 years "*little or nothing has been done*" to rebuild the city that was later devastated of the catastrophe. "*There are families that still live on mats and plastics*." The earthquake of 7.9 degrees, left 595 dead, about 2,291 injured, 76 thousand houses destroyed and 431 thousand people affected [4].

Also, after two years of the earthquake that occurred in Colca (Caylloma – Arequipa – Peru) families from Ichupampa continue to live in plastic modules, the reconstruction did not reach 15% of the houses affected by the earthquake of August 14, 2016. Of the 410 houses, only six were left intact, 234 were found collapsed and the rest suffered several cracks and fissures. The only church in the town was destroyed like the initial school. Two years have passed since the tragedy and the streets express that the earthquake had occurred last week. According to the Commerce of August 15, 2018, only 132 were qualified to be rebuilt and each house will be served with the S/43,348 bond and to date, only one house has been rebuilt [5].

2. Methodology

Science shows that the practice of comparison has been and continues to be an essential resource for responding to problems of natural and social knowledge. But we must not forget the important differences that exist between comparison as a way of thinking and as a scientific procedure. The first compares simple operations; the second compares complex operations, although the difference does not lie in the complexity of the logical structure of the comparisons, does not present significant contrasts in science and in everyday life, but rather 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 data analysis from which the comparisons are made [6].

The comparative method consists of empirical generalization and hypothesis verification. The advantages offered by the comparative method include understanding unknown things from known ones, the possibility of explaining and interpreting them, profiling new knowledge, highlighting the peculiarity of known phenomena, systematizing information, distinguishing differences with similar phenomena or cases [7].

The comparative method is inherent in any scientific procedure, it is expected that whenever it is compared following scientific procedures, it will be possible to compare; in aspects that are comparable and follow the analysis strategy to reach conclusions. It is not understood any type of unconscious comparison, that is not premeditated, rather this comparison is based on established objectives [6].

> *For the comparison process, on the one hand, there are single-family houses designed and built with pre-manufactured elements of reinforced concrete and on the other hand, there is a confined masonry design and construction*.

The methodological process to follow is defined in three phases:

2.1 Phase 1

Architectural design of basic single-family houses: It comprises the architectural design of twelve types of single-family houses with one story, which in turn will be the basis for building a second story in the future. The design corresponds to six houses with prefabricated elements and six houses with confined masonry, in both cases the useful surface is the same.

2.2 Phase 2

Structural Design of basic single-family houses and building process: Includes the structural design of basic single-family houses, using the calculation process. For both manufactured houses and confined masonry designed houses. Building processes are also defined.

2.3 Phase 3

Analysis of costs, budgets and times for the construction of basic single-family houses: The designs and processes are analyzed according to the specified and delimited approaches. In order to define the costs, the budget and the times that the building demands. The analysis of results must achieve:

- Design construction processes for the building.
- Establish the shortest construction time for the building.
- Establish the lowest cost of manufacture, construction and building.

3. Results

3.1 Design and development of basic housing

The design was carried out according to the requirements of the comparative method, in order to observe the data of the proposed variables and indicators. Architectural and structural designs and construction processes are analyzed.

In order to define the costs, the budget and the times required for the construction of the houses. The houses designed is the result of an exploration of the housing need of the City of Arequipa and nearby cities affected by telluric processes.

The dominant design principle is the useful surface of the environments of the designs are equal, that is, the useful areas of a bedroom, is the same in both types of design (precast and confined masonry), as well as in all the components of the living place. The outstanding and visual difference is in the thickness of the walls, in the prefabricated house it is 0.10 meters and in the houses with confined masonry it is 0.15 m. The total area that a manufactured house occupies is less than a house with confined masonry.

3.1.1 Prefabricated basic single-family housing (VUF)

Six types of basic single-family housing of various lengths and widths were designed, whose representative product on the surface are: 25.83 m^2, 33.39 m^2, 39.06 m^2, 42.21 m^2, 51.03 m^2 and 59.85 m^2 (**Tables 1–3**; **Figures 1–6**).

3.1.2 Basic single-family house-confined masonry (VAC)

The six types of basic single-family housing built by confined masonry of various dimensions of length and width whose representative product on the constructed area are: 27.09 m^2, 35.15 m^2, 41.28 m^2, 44.51 m^2, 53.54 m^2, 63.86 m^2 (**Tables 4–6**).

Items	Basic Housing	Long m	Wide m	T. Area m^2	Code
1	Prefabricated Single Family Housing 01	6.30	4.10	25.83 m^2	VUF 01
2	Prefabricated Single Family Housing 02	6.30	5.30	33.39 m^2	VUF 02
3	Prefabricated Single Family Housing 03	6.30	6.20	39.06 m^2	VUF 03
4	Prefabricated Single Family Housing 04	6.70	6.30	42.21 m^2	VUF 04
5	Prefabricated Single Family Housing 05	8.10	6.30	51.03 m^2	VUF 05
6	Prefabricated Single Family Housing 06	9.50	6.30	59.85 m^2	VUF 06

Table 1.
Areas and codes of prefabricated single-family housing.

Environments in square meters (m^2)	VUF 01	VUF 02	VUF 03	VUF 04	VUF 05	VUF 06
Kitchen, dining room and living room.	13.00	12.36	14.2	18.9	23.7	21.4
Bedroom: a 2/seater bed	7.50	7.5	7.5	7.5	8.76	8.76
Bedroom: two 1/square beds		7.5	7.5	7.5	7.5	7.5
Bedroom: two 1/square beds						7.5
Bathroom, toilet, sink and shower.	2.60	2.6	2.6	2.6	2.6	2.6
Bathroom, toilet, sink and shower.					2.6	2.6
Passage			3.06	1.2	1.26	1.26
Walls	2.73	3.43	4.20	4.51	4.61	6.97
Total Area m^2	25.83	33.39	39.06	42.21	51.03	58.59

Table 2.
Detail of environments by surface in square meters – VUF.

Environments in percentage (%)	VUF 01	VUF 02	VUF 03	VUF 04	VUF 05	VUF 06
Kitchen, dining room and living room.	50.33	37.02	36.35	44.78	46.44	36.53
Bedroom: a 2/seater bed	29.04	22.46	19.20	17.77	17.17	14.95
Bedroom: two 1/square beds		22.46%	19.20	17.77	14.70	12.80
Bedroom: two 1/square beds						12.80
Bathroom, toilet, sink and shower.	10.07	7.79	6.66	6.16	5.10	4.44
Bathroom, toilet, sink and shower.					5.10	4.44
Passage			7.83	2.84	2.47	2.15
Walls	10.57	10.27	10.75	10.68	9.03	11.90
Total Area %	100.%	100.%	100.%	100.%	100.%	100.%

Table 3.
Detail of the environments in percentage of occupancy – VUF.

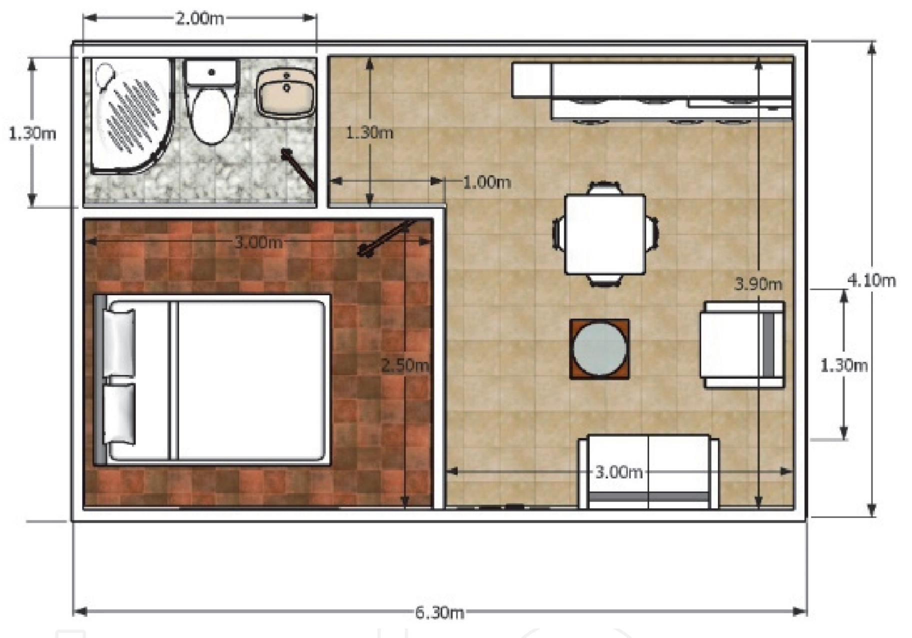

Figure 1.
Plant view VUF 01.

3.2 Isometry of basic single-family houses

Isometric projection allows us to show basic housing in three-axis dimensions (height, width and depth) allows us to understand the desire of the work to achieve. It is practically a cube of variable dimensions, where the basic characteristics of a house are shown.

3.2.1 Isometry in prefabricated houses with elements of reinforced concrete

It has been projected in this way in order to reduce costs to a minimum. Common measures are used. The front view, is 6.30 m long, the free height is 2.40 m, the doors, windows and some rooms have the same dimensions that provide a minimum surface of habitability. This reduces production costs and increases its efficiency on the production line (**Figure** 7).

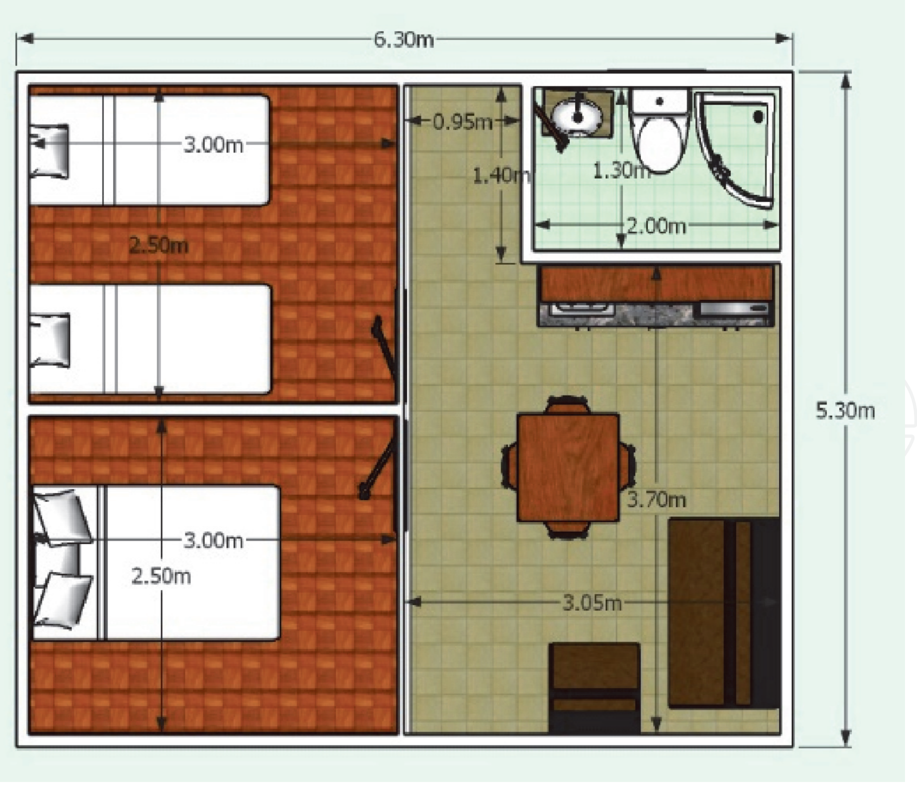

Figure 2.
Plant view VUF 02.

Figure 3.
Plant view VUF 03.

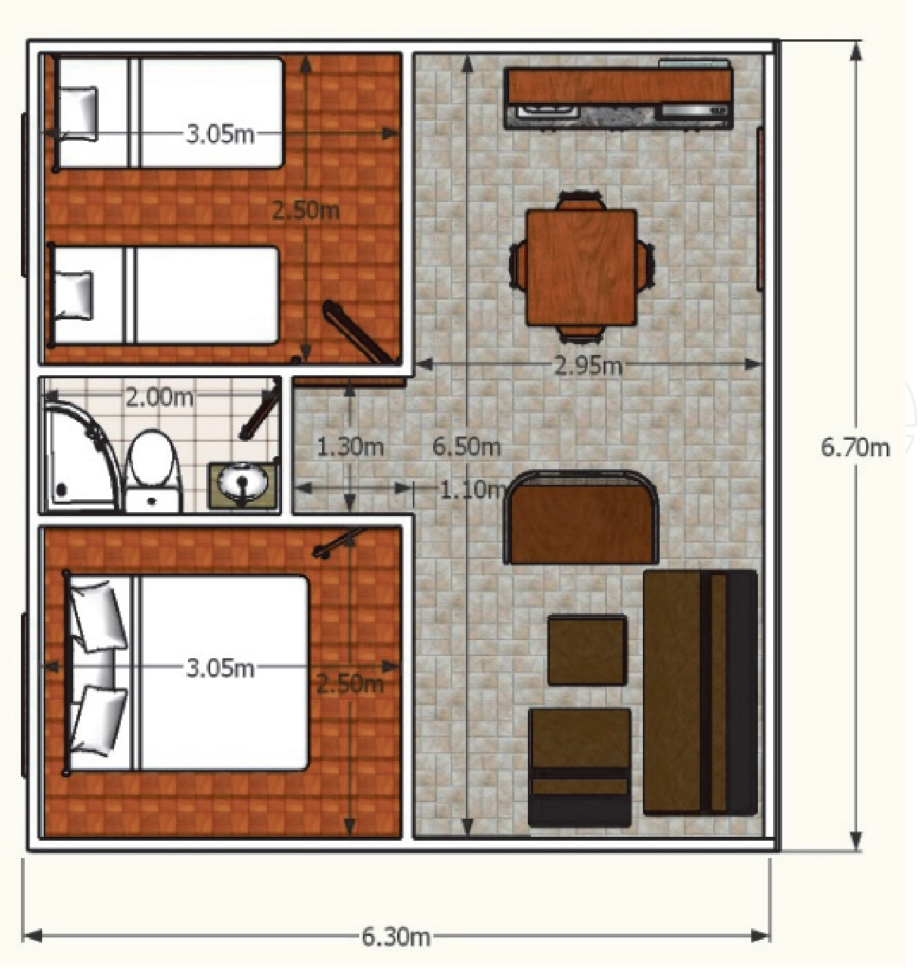

Figure 4.
Plant view VUF 04.

The view is common and its unique perspective, which differs externally between each other are longitudinal dimensions and the number of windows, the details are specified in the floor views.

3.2.2 Isometry in prefabricated houses with confined masonry

The isometry of houses with confined masonry is as similar as those built with prefabricated elements with reinforced concrete element s. The view is common and the singular perspective, which differs externally between them are the different dimensions of length and width, which implies a larger surface area, expressed in different values.

3.3 Process of elaboration of precast reinforced concrete elements

In the manufacturing process, equipment and machines are used that must have the property of moving them to a place with minimal conditions and can be established in nearby places where prefabricated houses are assembled.

The machines and equipment to be used are:

- Portable laboratory for design and testing.
- Devices for loading, storage and dosing of supplies.
- Self-propelled concrete mixer or purchase ready-mix concrete.

Figure 5.
Plant view VUF 05.

- Independent molds, with horizontal and vertical movement.
- Independent vibration or additive platform.
- 10 TM combustion engine forklifts.
- 10TM truck crane with a 10 m free platform.
- Manual tools.

The manufacturing process requires having molds to make the prefabricated elements. The molds respond directly to the design and must respond to the requirements of the projects. Efficiency is increased when a mold or a small number of molds can be so versatile and can produce a wide variety of precast elements.

A 2.40 m x 9.60 m mold has been designed with a variable mold thickness from 0.10 m to 0.40 m, designed from iron plate, having to have several molds that can give shape to pieces of variable configuration. There must be space for doors and windows, it must allow to place the sanitary and electrical installations. You can also use wooden formwork to expose a glossy finish.

Concrete to achieve the projected strength must be subjected to a vibration process. The designed system consists of placing the molds on rails with a vibration

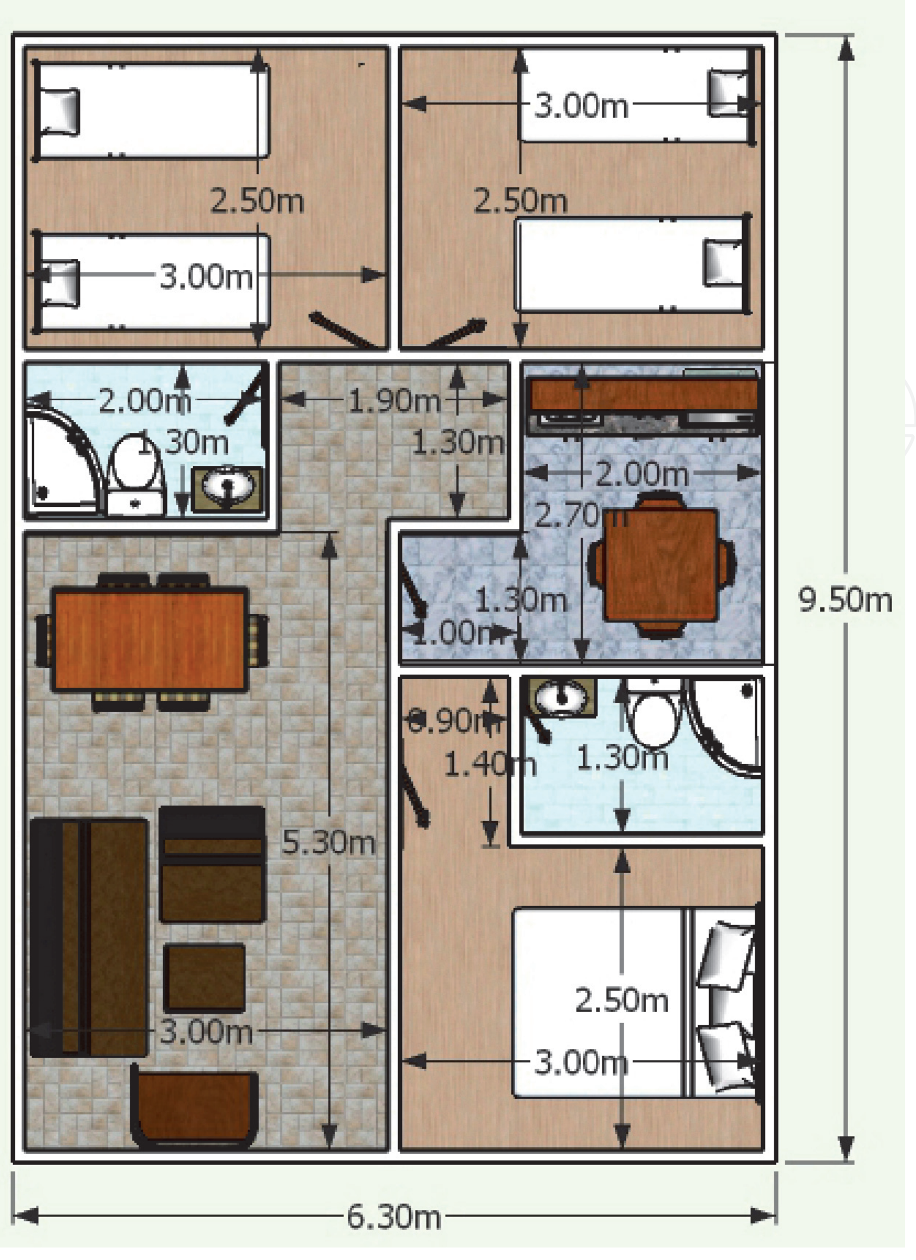

Figure 6.
Plant view VUF 06.

Items	Basic Housing	Long m	Wide m	T. Area m^2	Code
1	Confined Masonry Housing 01	6.45	4.20	27.09 m^2	VAC 01
2	Confined Masonry Housing 02	6.45	5.45	35.15 m^2	VAC 02
3	Confined Masonry Housing 03	6.45	6.40	41.28 m^2	VAC 03
4	Confined Masonry Housing 04	6.90	6.45	44.51 m^2	VAC 04
5	Confined Masonry Housing 05	8.30	6.45	53.54 m^2	VAC 05
6	Confined Masonry Housing 06	9.75	6.55	63.86 m^2	VAC 06

Table 4.
Areas and codes of single-family housing confined masonry VAC.

platform. When the production of precast elements moves to another location the vibration process is replaced with the use of additives, depending on the cost, the use of additives can replace the physical vibration process.

Environments in m^2	VAC 01	VAC 02	VAC 03	VAC 04	VAC 05	VAC 06
Kitchen, dining room and living room.	13.00	12.33	14.35	19.94	23.4	21.72
Bedroom: a 2/square bed	7.50	7.5	7.5	7.63	7.5	7.63
Bedroom: two 1/square beds		7.5	7.5	7.63	7.5	7.63
Bedroom: two 1/square beds						7.63
Bathroom, toilet, sink and shower.	2.60	2.6	2.6	2.6	2.6	2.6
Bathroom, toilet, sink and shower.					2.6	2.6
Passage			2.93	1.37	2.47	5.13
Walls	3.99	5.22	6.40	6.03	7.47	8.92
Total Area in m^2	27.09	35.15	41.28	45.20	53.54	63.86

Table 5.
Detail of the environments by surface in square meters – VAC.

Environments in percentage (%)	VAC 01	VAC 02	VAC 03	VAC 04	VAC 05	VAC 06
Kitchen, dining room and living room.	47.99	35.08	34.76	44.12	43.71	34.01
Bedroom: a 2/square bed	27.69	21.34	18.17	16.88	14.01	11.95
Bedroom: two 1/square beds		21.34	18.17	16.88	14.01	11.95
Bedroom: two 1/square beds						11.95
Bathroom, toilet, sink and shower.	9.60	7.40	6.30	5.75	4.86	4.07
Bathroom, toilet, sink and shower.					4.86	4.07
Passage			7.10	3.03	4.61	8.03
Walls	14.73	14.85	15.50	13.34	13.95	13.97
Total Area	100.%	100.%	100.%	100.%	100.%	100.%

Table 6.
Detail of the environments in occupancy percentage – VAC.

The process for making precast elements is as follows:

- Define the design of the basic single-family house.
- Preparation of elements to be prefabricated.
- Formwork – molding, placement of meshes and pipes.
- Pouring of ready-mixed concrete.
- Physical vibration or with additives.
- Finishes and accumulation of pieces and cataloging.
- Transport and assembly.

3.4 Assembly of a prefabricated house with elements of reinforced concrete

The assembly process, perform the following process (**Figure 8**).

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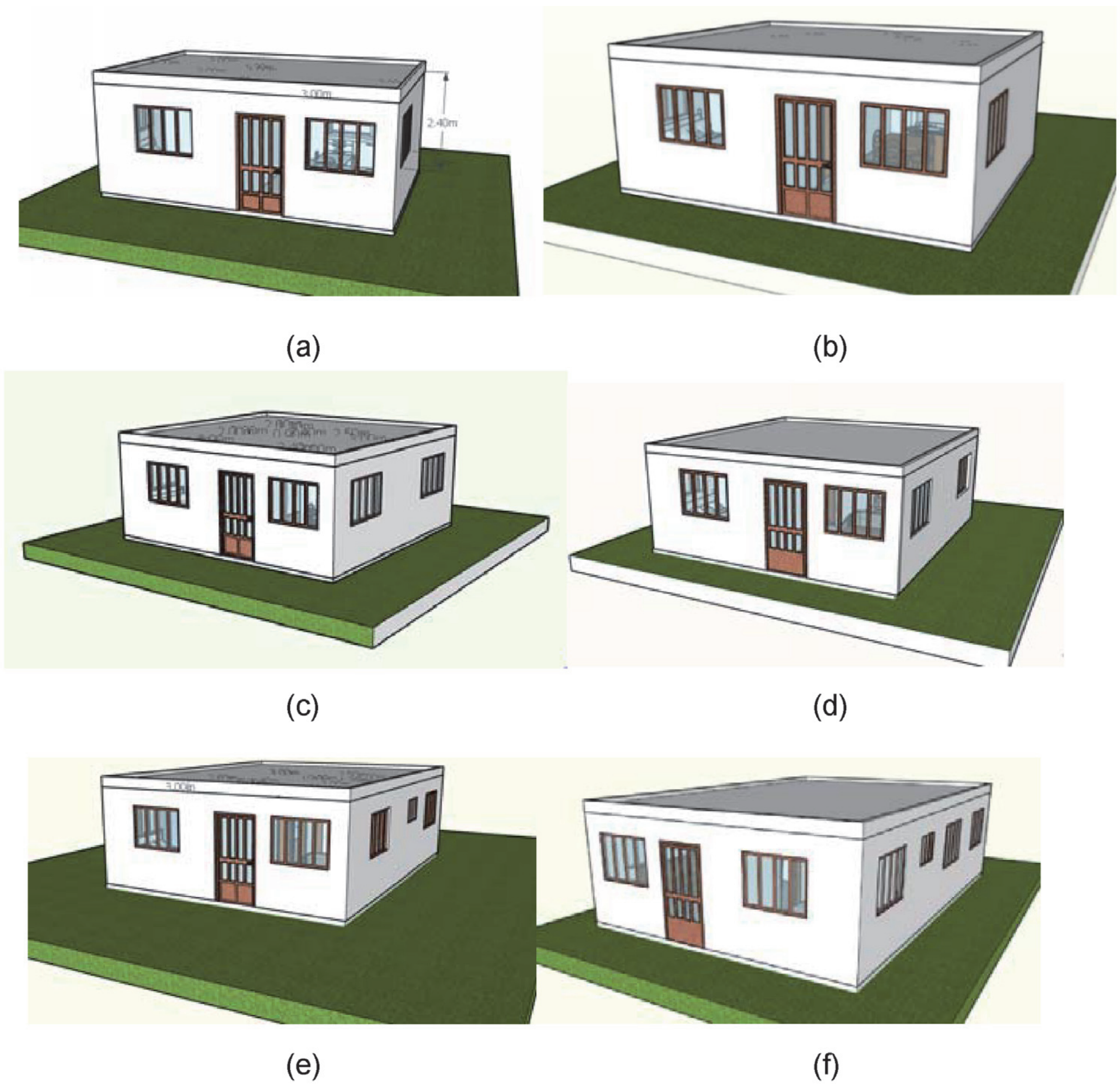

Figure 7.
(a) Isometric view of VUF 01. (b) Isometric view of VUF 02. (c) VUF 03 isometric view. (d) VUF 04 isometric view. (e) VUF 05 isometric view. (f) VUF 06 isometric view.

3.5 Structure of prefabricated elements of reinforced concrete

The structural system of precast concrete elements comprises foundation beams, floor slabs, walls and ceiling, under an approach of articulated structural panels with anchors that support stress requests. The elements must reach a sufficient resistance for their handling and transport to the assembly place. They must withstand the weather and inclement places.

Each element is made of reinforced concrete 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 in the perimeter near the edge there is an iron with diameters of 1/2″ in diameter, reinforcements are also applied in corners and critical places. Lifting and transport devices are installed. It is possible to use various anchoring systems, as long as it responds to the stress requests required by the prefabricated parts.

Two pieces are shown with exposed structures, the others show a similar constitution (**Figure 9**).

3.6 Production time and assembly of a prefabricated house

For this analysis, we worked with the value of the unit time, which is the direct relationship between the metering and the unit yield of the item, in relation to the

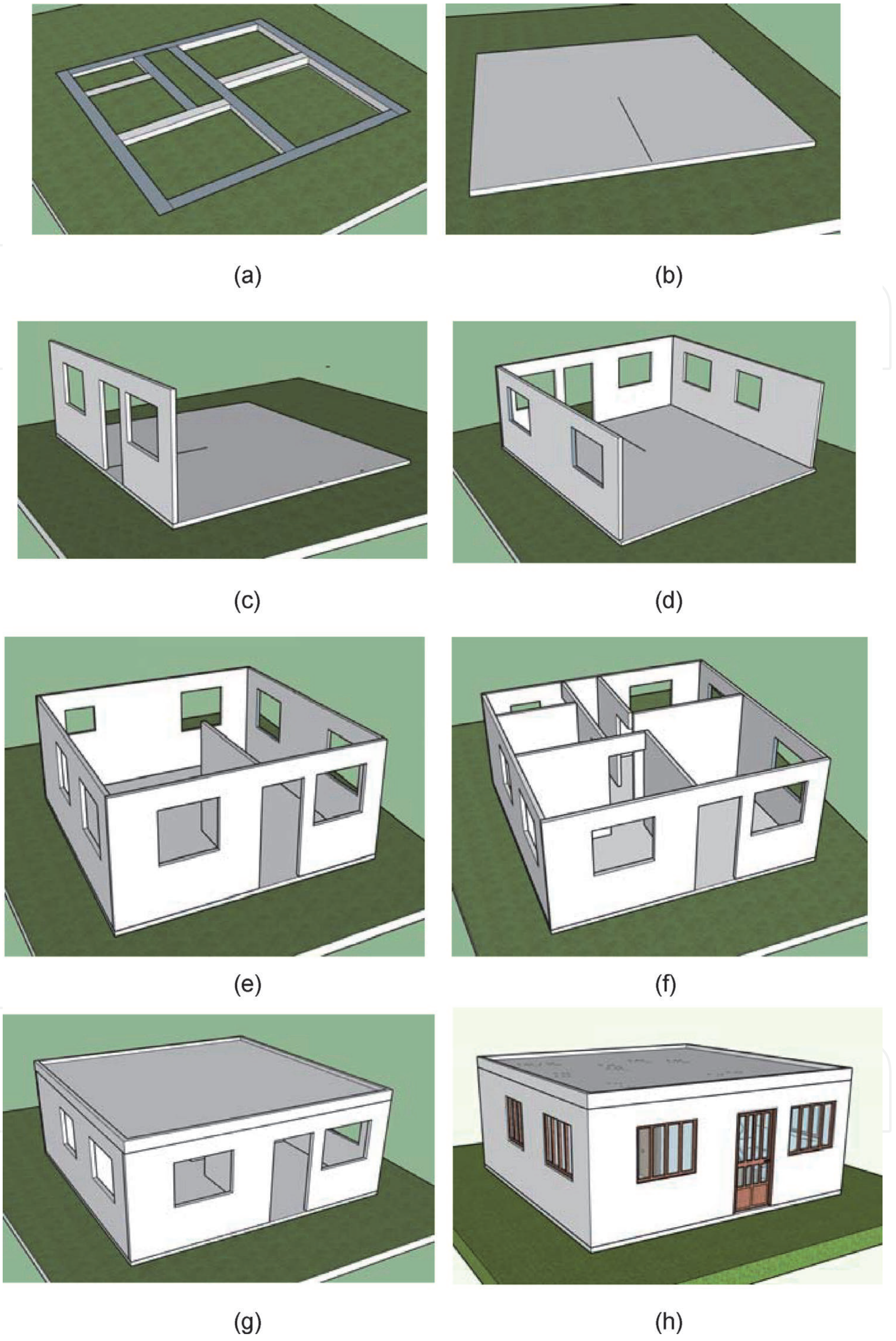

Figure 8.
(a) Foundation installation. (b) Foundation slab. (c) Front wall installation. (d) Installation of sidewalls. (e) Installation perimeter wall. (f) Installation of interior walls. (g) Ceiling installation. (h) Completion of work finishes.

value of the direct cost. The individual values per item and the total per dwelling, were obtained according to the S10 program, which gives us a gross unit time of the need in days and that is required for the execution of the work.

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The value obtained is an indicative and orientate parameter that allows us to adjust the necessary times, according to an adjusted time analysis of unit times and the Gantt chart is made. The minimum and effective duration of production and assembly of the prefabricated houses has been determined, which are shown in the following (**Table 7**).

The unit time of VUF Prefabricated Single Family Housing has been determined from 32.07 days in VUF-01 to 65.70 days in VUF 06. Adjusted time with a Gantt diagram of VUF Prefabricated Single Family Housing has been determined from 4.00 days in VUF-01 to 6.00 days in VUF 06 (**Figure 10**).

El Unitary time of VUF houses is adapted to a quadratic polynomial trend of y x $0.005x^2$ + 0.6022x + 12,706 (R2 x 0.9916, 95%). El Adjusted Unit Time in Gantt of

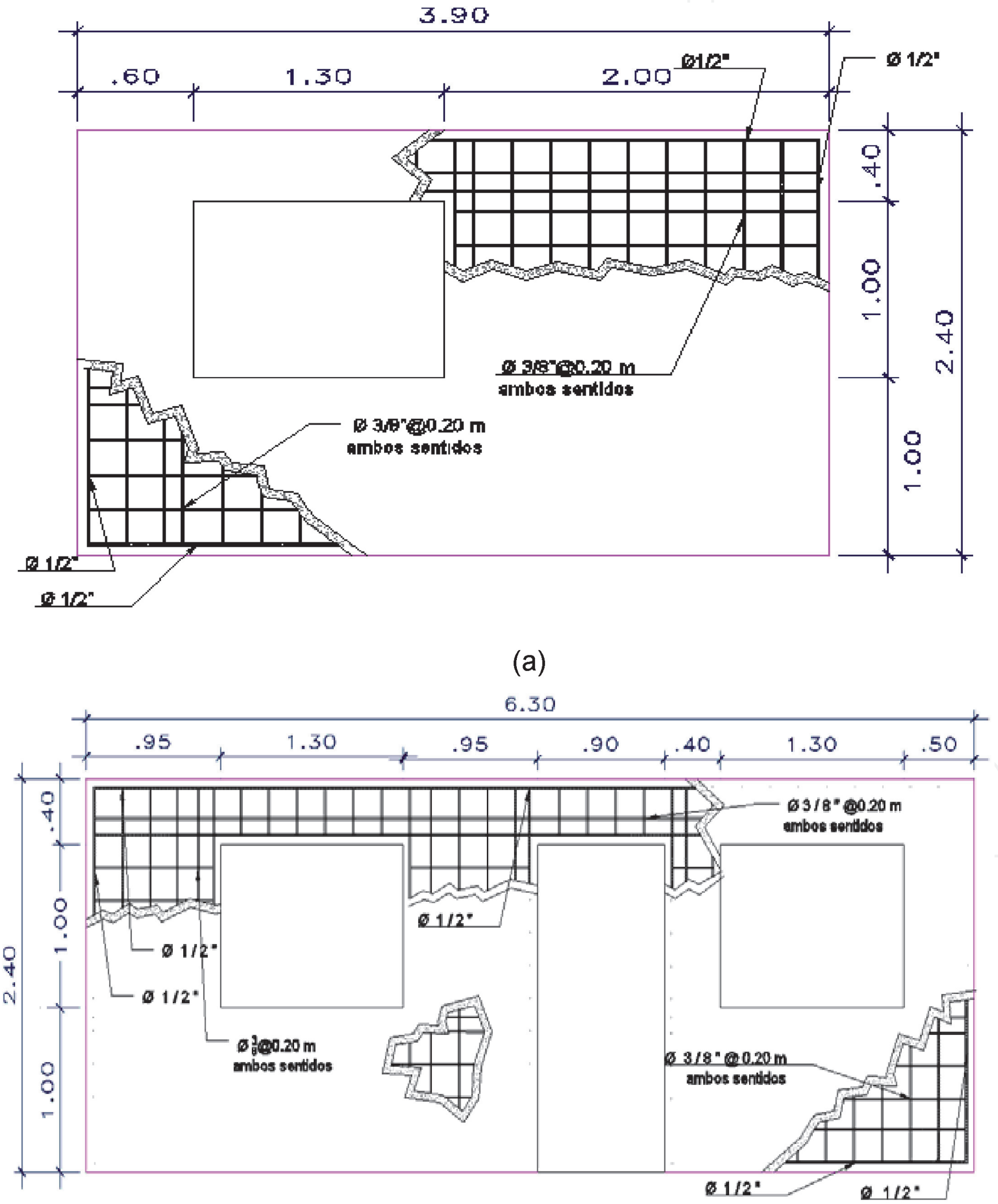

Figure 9.
(a) Structure of a side piece with window of the VUF 01. (b) Structure of a front part of the VUF 01.

VUF houses is adapted to a quadratic polynomial trend of y – 0.0003x^2 + 0.0876x + 2,004, (R2 x0.9072, 95%).

The unit time on constructed housing area expressed in days/m^2, has been determined, the lowest value in VUF-04 of 1.09 and the highest value found in VUF-01 of 1.24. Performing calculations at set times in the Gantt chart has achieved the lowest value in VUF-06 of 0.10 and the highest value in VUF-01 of 0.15.

These indices are achieved without increasing the efficiency of the machines and equipment, by carrying out a greater analysis with efficiency indices, the production level would increase and achieve cost reduction, which implies producing larger units of prefabricated elements per unit of time. There is a direct relationship between execution times and investment requirements, it is shown in the following (**Table 8**).

It presents a direct relationship between the execution days and the investment requirement, expressing that, the greater the number of execution days, the greater the investment. The largest investment is concentrated in the production of prefabricated parts.

Description	VUF Air m^2	T. U. Metrado/Ru days VUF	T. A. Gantt, VUF days.	T. U. days/ m^2	T. A. Gantt days/m^2
VUF-01:	25.83	32.07	4.00	1.24	0.15
VUF-02:	33.39	37.88	4.88	1.13	0.15
VUF-03:	39.06	43.99	4.66	1.13	0.12
VUF-04:	42.21	45.84	5.00	1.09	0.12
VUF-05:	52.29	59.90	6.00	1.15	0.11
VUF-06:	59.85	65.70	6.00	1.10	0.10

Table 7.
Unit time (TU) and adjusted (TA) in VUF Gantt.

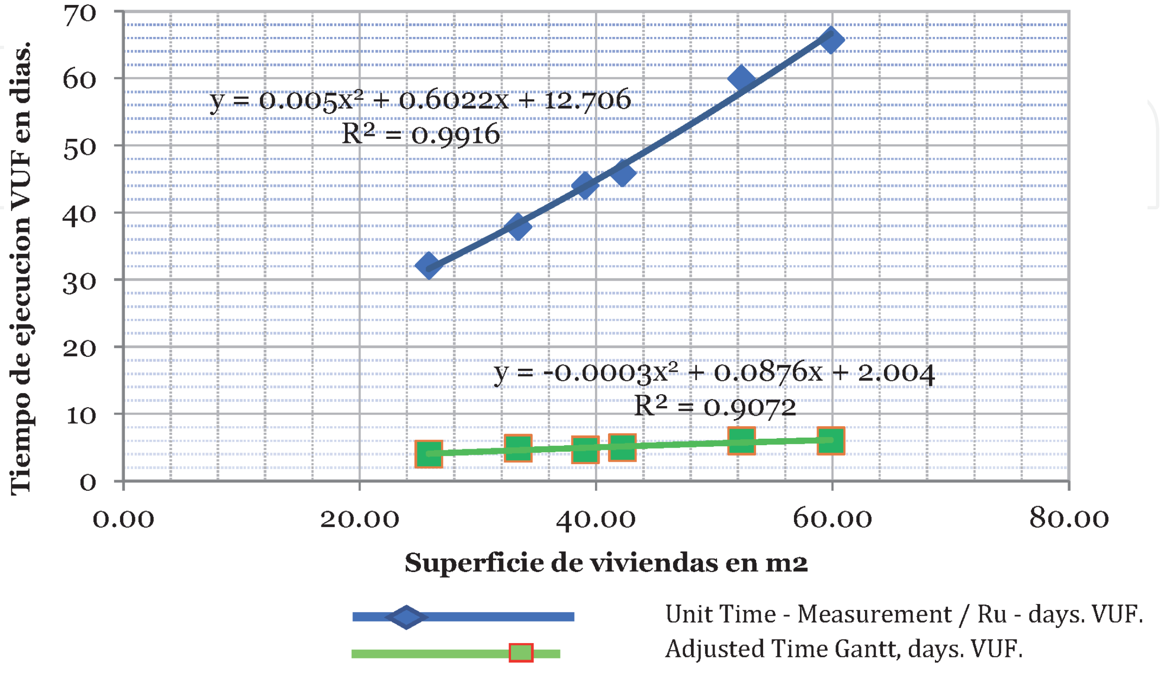

Figure 10.
Unit time and adjusted execution of the VUF.

The investment trend responds to a cubic polynomial function where the cusp is on the second day of execution, there is a decrease on the fourth day. However, it must be understood that the work can be executed within four to six days, therefore, before starting the execution of works all available investment must be available (**Table 9**).

Of the trends of the polynomial functions, there are three subtypes in the relationship of execution time and investment requirement, which is expressed in three values close to 1 of the coefficients of determination. Which tells us that according to the sub types of prefabricated houses, the cost of the work and the investment requirements can be adjusted (**Figure 11**).

3.7 Costs and budgets of VUF prefabricated single-family houses

3.7.1 Direct costs VUF

The direct cost are all those expenses that are directly related to the construction of a work, specifically it will be expressed in the amount of labor, materials and equipment involved in the execution of a work, which will be expressed in national currency and in US dollars at the change of budgeting.

Six types of houses have been designed for a production system of prefabricated elements of single-family houses in order to optimize resources and adapt to a minimum production line at scale, be it on a production line in plant or at the foot of the play.

Architectural and structural plans have been developed for each type of house designed, from which the corresponding measurements have been made. These

Description	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	TOTAL
	1.dia	2.dias	3.dias	4.dias	5.dias	6.dias	
VUF-01	8,428	13,994	9,558	6,710			38,690
VUF-02	8,929	17,542	11,884	4,083	4,308		46,745
VUF-03	11,605	18,043	6,753	12,889	5,101		54,391
VUF-04	11,079	19,258	7,402	12,063	5,672		55,475
VUF-05	15,217	25,297	8,893	11,942	6,612	4,647	72,608
VUF-06	19,602	25,437	9,392	14,877	5,590	6,346	81,244

Table 8.
VUF daily investment requirement.

Code	Inversion polynomial functions	R^2
VUF 01	$y = 1931.4x^3 - 16589x^2 + 41813x - 18727y$	R^2 = perfecta.
VUF 02	$y = 1858x^3 - 18074x^2 + 49687x - 24514$	$R^2 = 0.9996$
VUF 03	$y = 316.89x^3 - 3639.7x^2 + 10388x + 5489.6$	$R^2 = 0.4056$
VUF 04	$y = 748.51x^3 - 7638.2x^2 + 21273x - 2388.3$	$R^2 = 0.469$
VUF 05	$y = 608.77x^3 - 6676.6x^2 + 18265x + 4691$	$R^2 = 0.6687$
VUF 06	$y = 469.56x^3 - 4901.2x^2 + 11242x - 14014$	$R^2 = 0.7084$

Table 9.
Inversion polynomial functions VUF.

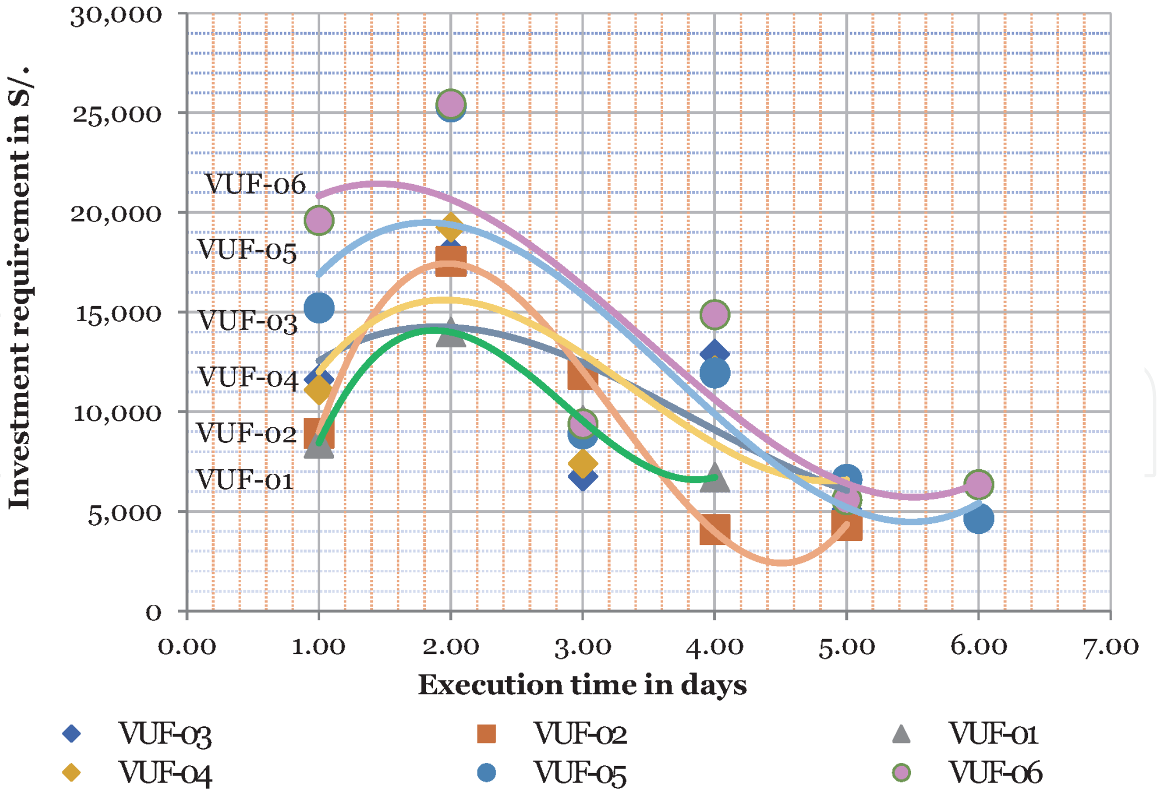

Figure 11.
Polynomial lines trend reversal time in execution VUF.

measurements were processed in the cost and budget program S10. A summary of direct costs is presented in the **Table 10** below.

Description	Cost in Soles	Cost in Dollars	Cost in $/m^2
Direct Cost VUF-01	27,323.20	7,786.61	301.46
Direct Cost VUF-02	33,012.08	9,407.83	281.76
Direct Cost VUF-03	38,411.45	10,946.55	280.25
Direct Cost VUF-04	39,176.99	11,164.72	264.50
Direct Cost VUF-05	51,277.09	14,613.02	279.46
Direct Cost VUF-06	57,375.35	16,350.91	273.20
T/C: 3,509 to 26 June 2020, SUNAT-PERU [8].			

Table 10.
Direct cost of a VUF in US suns and dollars.

The costs of the manufactured houses shown in the table are in Peruvian currency in soles, in US dollars and the cost per square meter, according to the type of VUF house. For each item, a unit cost analysis has been carried out indicating the amount of materials used and considers the equipment and machines necessary for its manufacture and assembly (**Figure 12**).

The direct costs in dollars of basic housing range from US $ 7,786.61 to US $ 16,350.91 and are accessible to the economies of populations in need of housing. These prices are competitive with the costs offered in the real estate industry.

The bond that the Peruvian government assigns to the victims of collapsed or uninhabitable houses due to disasters according to RM No. 012 2018 Housing [9] establishes a housing reconstruction bond for Ichupampa, Lari, Tuti and others in Arequipa, of S/43,497 y its value in US dollars is $ 13,171.

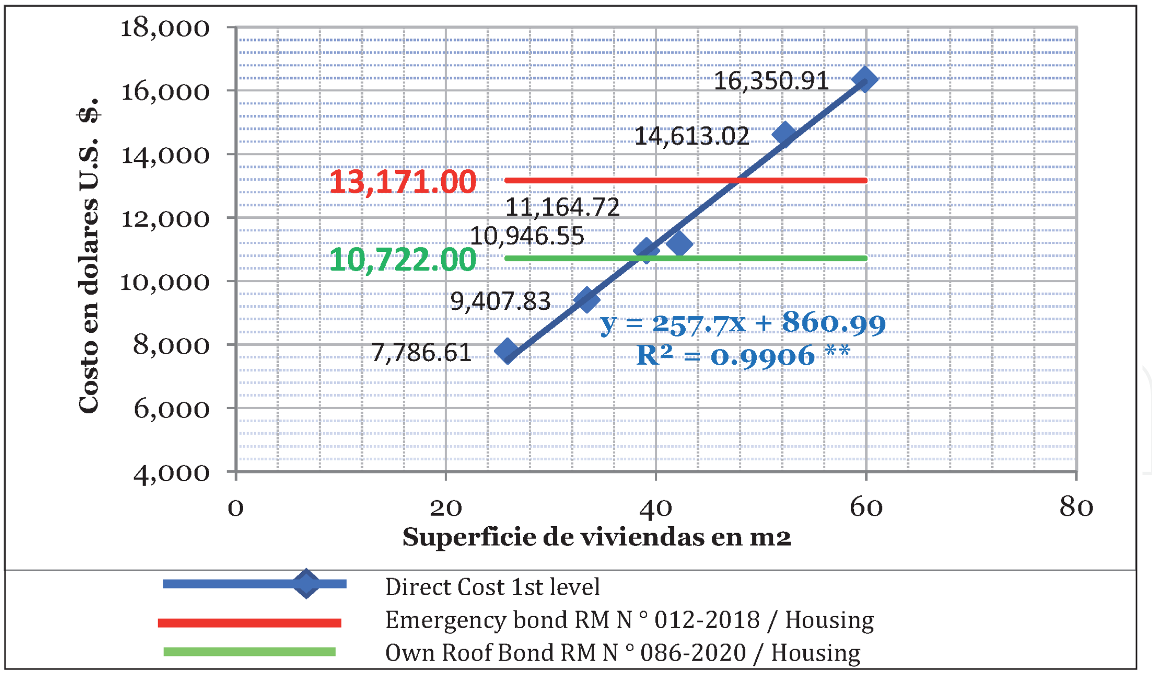

Figure 12.
Direct cost of VUF and its relationship to emergency bonds.

The value of the house VUF 01, VUF 02, VUF 03 and VUF 04 are below the bonus assigned by the Peruvian Government. The proposal to serve in situations of need for housing and post-emergency is framed for direct care, effectively and in a short period of time. The correlation analysis between the surface of the VUF and the cost in dollars of its building has a linear trend and the coefficient of determination is very high.

The direct cost per square meter of manufactured housing, in US dollars, ranges from $ 273.23 to $ 301.46, these amounts are one of the lowest compared to traditional construction costs.

According to Ministerial Resolution No. 086–2020-Housing [10] it provides a family housing bonus for families in need of S/. 37,625 soles, in US dollars it is equivalent to US $ 10,722.43 and VUF 01 and VUF 02 houses are below this value.

3.7.2 Total costs. VUF

The total cost of a work is defined as the sum of direct cost-plus indirect costs. For our case, indirect expenses are covered by overheads of 10% of direct cost plus 10% profit; from which a subtotal is obtained and from this value is added 18% corresponding to the IGV, resulting in the total cost. For a production line it is common for indirect cost to be a fixed and non-alterable proportional value in costing processes.

The value of the total cost has been obtained in soles and then it has been converted to US dollars according to the exchange rate and the cost per square meter is established in US dollars (**Table 11**).

The total costs in dollars of basic housing range from US $ 11,025.83 to US $ 23,152.89 and are accessible values for the economies of populations in need of housing (**Figure 13**).

The bond that the Peruvian government assigns to the victims of collapsed or uninhabitable houses due to emergencies or disasters according to RM No. 012 2018 Housing The housing reconstruction bond of US $ 13,171 would only allow VUF 01 and VUF 02 to be reached.

Description	Cost Soles	Cost Dollars	VUF Area	Cost in $/m^2$
C.T. VUF-01	38,689.65	11,025.83	25.83	426.86
C.T. VUF-02	46,745.11	13,321.49	33.39	398.97
C.T. VUF-03	54,390.61	15,500.32	39.06	396.83
C.T. VUF-04	55,474.62	15,809.24	42.21	374.54
C.T. VUF-05	72,608.36	20,692.04	52.29	395.72
C.T. VUF-06	81,243.50	23,152.89	59.85	386.85

T/C 3,509 to 26 June 2020, SUNAT-PERU.

Table 11.
Total cost of prefabricated single-family housing (VUF).

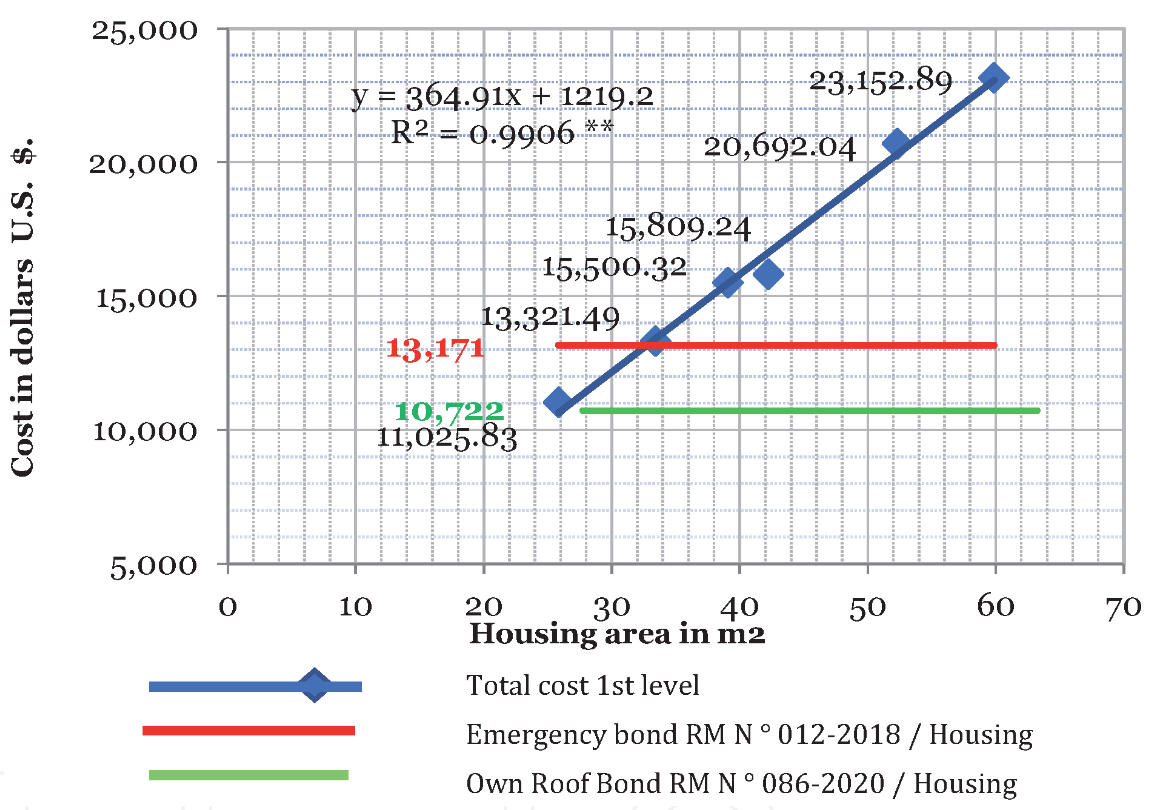

Figure 13.
Total cost of VUF and its relationship to emergency bonds.

The bonus that the Peruvian government assigns for its own roof according to Ministerial Resolution No. 086–2020-Housing of $ 10,722.43 US dollars would only be enough for VUF 01.

It is necessary to highlight that the bonds assigned to the population in need with the amounts assigned are incorporating 100% of the amount in the construction of a house, and under these conditions the recipient population can have a house without any particular investment contribution from the beneficiary. At present, it is usual for the beneficiary who receives these bonds to make a larger contribution to the received bonus, in some cases it can exceed up to five times the amount, and in many cases the desired house is not completed.

The correlation analysis of the total cost and the construction area of the VUF has a parallel, increasing linear trend and the coefficient of determination is very high and is the same value as that obtained in the direct cost.

The trend line of the direct cost, the coefficient of determination, is y = 257.70x + 860.99 R^2 = 0.9906. The trend line of the Total cost and the coefficient of determination is y = 364.91x + 1219.2 R^2 = 0.9906.

It is usual to calculate the cost trend in a production line from the direct cost, and on this amount an additional percentage is assigned to the value of the production line, which does not alter the cost trend. In our case, the value added to the specific direct cost is proportional and unalterable during the production and building processes, which is reflected in the trend lines and in the determination coefficient.

The direct cost per square meter of prefabricated housing, in US dollars ranges from $ 386.85 to $ 426.86, these amounts are low in comparison and are competitive costs with the real estate industry that exists in the city of Arequipa – Peru.

3.8 Cost separation and building times prefabricated VUF single-family housing and houses with VAC confined masonry

A comparison has been made between the design of a building with precast reinforced concrete elements and a traditional construction design that is known as confined masonry, it is a system that is traditionally used in Peru and Latin America.

The confined masonry is defined as that which is entirely bordered by elements of reinforced concrete (except for the foundations that can be made of cyclopean concrete and in other cases it is made of 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 construction sequence indicated so that the confinements adhere to the masonry and form a whole that acts in an integral way [11].

For this reason, six single-family houses built with confined masonry have been designed that have similar characteristics to those of single-family houses with prefabricated elements. That is to say, the architectural plans are similar with regard to the space of the architectural environments, the difference is found in the width of the walls in confined masonry, the width of the wall is 15 cm and in the precast it is 10 cm.

From which the anti-seismic structural calculations with response of equal magnitude have been modeled. Once this similarity was achieved, the metric analysis was then developed, and it was processed in the S10 cost and budget program, in the Microsoft Project and in the SPSS.

3.8.1 Comparison of building times VUF and VAC

The unit time of VUF Prefabricated Single Family Housing has been determined from 32.07 days in VUF-01 to 65.70 days in VUF 06 and the Time Adjusted with a Gantt chart has been determined from 4.00 days in VUF-01 to 6.00 days in VUF 06.

The unit time of the House built with VAC confined masonry has been determined from 61.11 days in VAC-01 to 136.39 days in VAC-06 and the Adjusted time with a Gantt chart has been determined from 35.38 days in VAC-01 to 79.20 days in VAC 06 (**Table 12**).

The shortest time required for the construction of houses is with prefabricated elements, it is due to the simplicity of the production and assembly process, whereas in confined masonry a dependent, time-consuming and stationary entangled process is required, which leads to lengthening the processes of completion of works.

Description	VAC areas	T. U. (Metrado/Ru) VAC days	T. A. Gantt VAC, days.	T. U. days/m^2	T. A. Gantt days/m^2
VAC-01	27.74	61.11	35.38	2.20	1.28
VAC-02	35.15	76.87	47.26	2.19	1.34
VAC-03	40.96	92.50	56.53	2.26	1.38
VAC-04	44.51	90.88	55.84	2.04	1.25
VAC-05	52.59	117.69	68.32	2.24	1.30
VAC-06	63.21	136.39	79.20	2.16	1.25

Table 12.
Unit time (TU) and adjusted time (TA) in VAC Gantt.

Houses with prefabricated elements require less time for their construction, in unit time values, it takes from 1.10 days/m^2 to 1.24 days/m^2. With time adjusted in Gantt, values lower than 0.10 days/m^2 to 0.15 days/m^2 are achieved.

On the other hand, in a confined masonry building process the time requirements/m^2 are higher, so in unit time 2.04 days/m^2 have been found to 2.24 days/m^2, in adjusted time it has been found from 2.04 days/m^2 to 2.26 days/m^2.

In the relationship between execution time and building surfaces for times adjusted by Gantt, for VUF, there is a polynomial trend of y = −0.0003x2 + 0.0876x + 2.004 and (R^2 = 0.9072) this trend is low in comparison to the VAC trend. For VAC, there is a polynomial trend of y = −0.0075x2 + 1.8927x – 10.777 (R^2 = 0.9879), this trend is very high compared to the VUF trend (**Figure 14**).

The trend of the construction processes of houses with confined masonry requires a longer time than for the processes of building houses with pre-manufactured elements. The VAC, the greater the construction area, the longer time is required for the building, whereas the VUF the building process in the

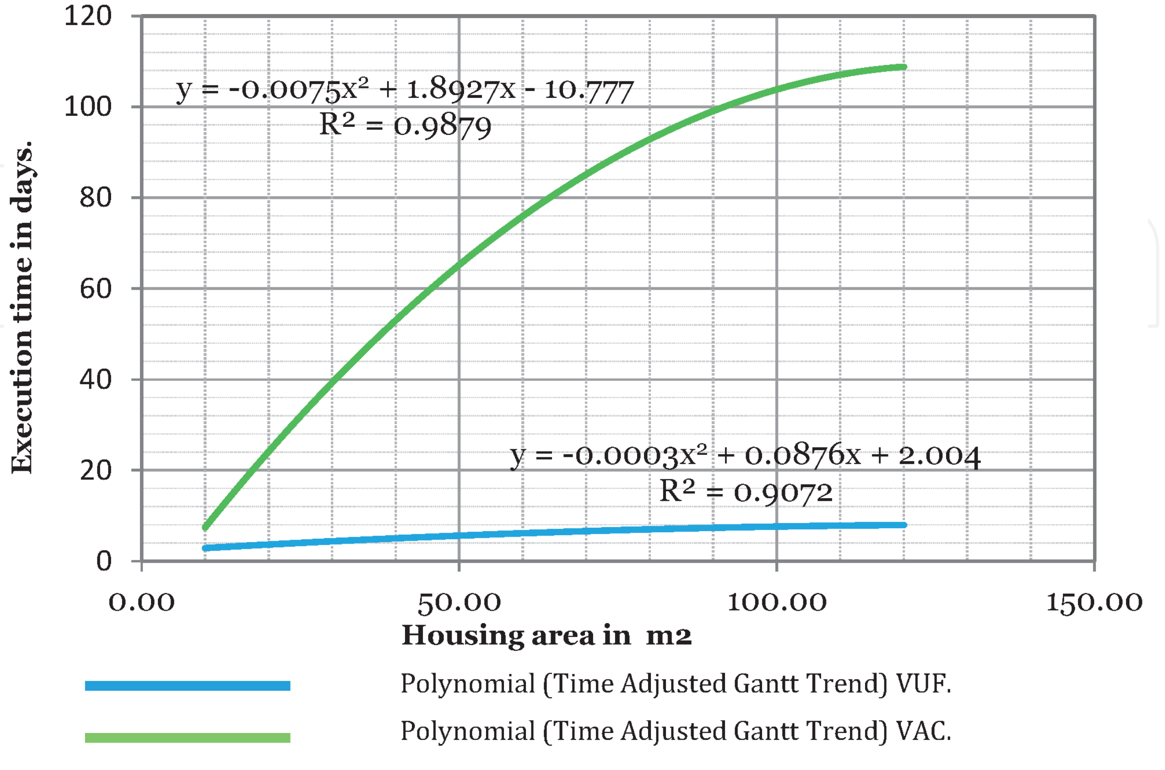

Figure 14.
Projected trend lines time/surface ratio of VUF and VAC.

surface variable there are no significant differences, this item is more dependent on the production capacity of machines and equipment.

3.8.2 Total costs VUF and VAC

From a common architectural design, the structural plans were developed and from which the metrics were measured and from which the housing costs were established, according to each type of housing designed, that is, 12 budgets were developed, with which the comparative analysis is carried out. By the comparative method, the principle of homogeneity and similarity was taken into account in order to make a comparison according to the proposed methodological design.

The design of items and costs of both building processes was developed from the same architectural design, expressed in a production line and trying to avoid falling into a comparative analysis of efficiencies, an aspect that is not considered in the research project. As a result of this process, the costs of the VUF and VAC single-family houses are presented (**Tables 13** and **14**).

Carrying out a conceptual contrast of the building processes by VUF precast elements in comparison with the construction processes by confined VAC masonry, the building with precast concrete elements exceeds in the reduction of time and costs, which has been reconfirmed in the calculations made (**Figure 15**).

According to the graphical representation of the costs of the VUF and the VAC, the cost difference is notable having the lower cost of the houses built with precast

Description	Cost in Soles	Cost in Dollars	VUF areas	Cost per m^2
C.T. VUF-01	38,689.65	11,025.83	25.83	426.86
C. T. VUF-02	46,745.11	13,321.49	33.39	398.97
C. T. VUF-03	54,390.61	15,500.32	39.06	396.83
C. T. VUF-04	55,474.62	15,809.24	42.21	374.54
C. T. VUF-05	72,608.36	20,692.04	52.29	395.72
C. T. VUF-06	81,243.50	23,152.89	59.85	386.85
T/C: 3,509 to 26 June 2020, SUNAT-PERU.				

Table 13.
Costs in suns and dollars of one (VUF).

Description	Cost in Soles	Cost in Dollars	VAC areas	Cost per m^2
C.T. VAC-01	56,959.17	16,232.31	27.74	585.16
C. T. VAC-02	70,700.67	20,148.38	35.15	573.21
C.T VAC-03	84,752.67	24,152.94	40.96	589.67
C.T. VAC-04	82,244.61	23,438.19	44.51	526.58
C.T. VAC-05	108,023.74	30,784.76	52.59	585.37
C.T. VAC-06	126,326.68	36,000.76	63.21	569.54
T/C: 3,509 to 26 June 2020, SUNAT-PERU.				

Table 14.
Costs in suns and dollars of an VAC.

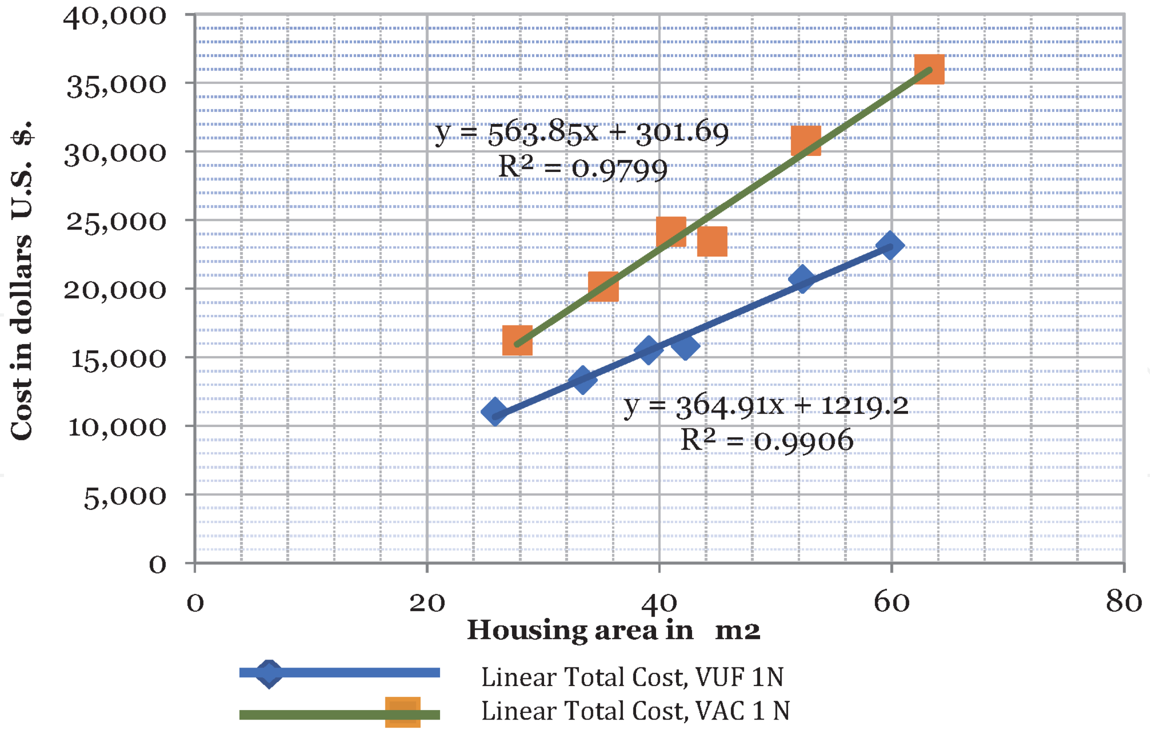

Figure 15.
Linear Total cost of VUF and VAC.

VUF concrete elements. The relation of total costs and surfaces for building processes, presents the following trend.

For VUF, a linear trend of y = 364.91x + 1219.2 (R^2 = 0.9906) is presented. This trend is very low compared to the VAC trend. Which shows that the VUF building costs are below the costs of a confined masonry building process.

For VAC, there is a linear trend of y = 563.85x + 301.69 and (R^2 = 0.9799) this trend is very high compared to the VUF trend. Which implies that VAC costs are high compared to VUF costs (**Figure 16**).

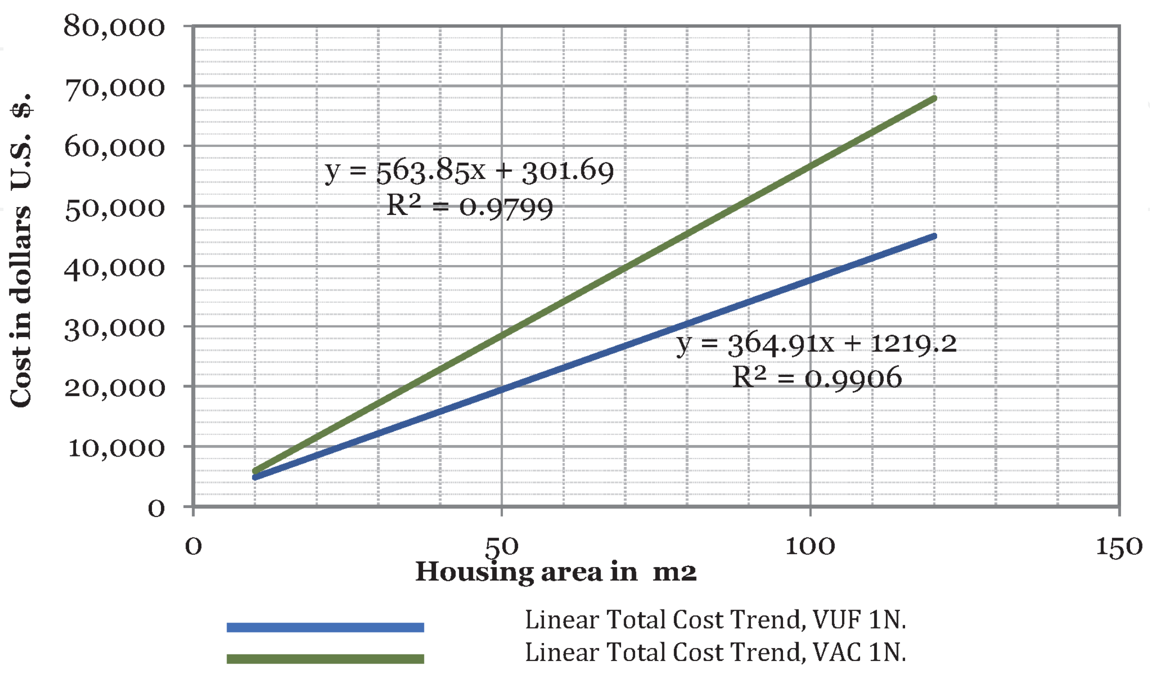

Figure 16.
Projected trend lines of cost/surface of VUF and VAC.

The projected trend of a VAC confined masonry building process exists a direct relationship and is determined by a coefficient of 0.9799 between cost in dollars and housing surface, which implies that the greater the built surface, the greater the investment and the slope of growth are required. is high. The trend of a VAC process significantly exceeds in costs a building process with VUF prefabricated elements, which allows confirming the efficiency of the VUF building process.

4. Conclusions

- Six types of basic single-family houses have been designed and are in accordance with the standards and are accessible to low-income economies. Four types of Housing to be served by the emergency bond granted by the Peruvian government in emergency situations and in need of housing.

- Parts and elements were designed for the assembly of prefabricated houses, seeking efficiency in terms of resistance and investment costs.

- A precast elements production line process was designed with minimal equipment that can be set up anywhere, even in post-emergency situations. The basic and fundamental criterion that the manufactured parts do not exceed the capacity of the size of the manufacturing, transport and assembly equipment.

- A process analysis was examined and a simple process was designed for the assembly of buildings, a minimum period of construction of a prefabricated house of 2 hours was determined at any time of the year.

- Lowest cost of a manufactured house fabrication and assembly system. Direct cost in VUF 04 has been achieved at a cost of US $ 264.50 per square meter and total costs of US $ 374.54 per square meter.

- There is a personal conviction to develop and make available a 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 a basic house or to solve the effects of a post-emergency situation. We hope to be able in the future to disseminate the knowledge achieved, after putting it into practice.

Author details

Guillermo Yorel Noriega Aquise
Catholic University of Santa María, Arequipa, Peru

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

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