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Industrialization, Efficiency and Social Housing: Sustainable Prefabrication for the Colombian Social and Cultural Context

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Abstract: This research aims to generate processes of industrialization and qualification of social housing in Colombia through prefabrication, low energy consumption and high environmental quality to reduce the current deficit and improve the quality of life in communities with fewer economic resources. Modular coordination and the use of materials with thermal behaviors, appropriate to the country's climatic characteristics, reduce production costs, avoid waste and improve the architectural and environmental quality of social housing. Passive cooling strategies, such as controlling solar incursion and generating natural cross ventilation eliminate energy consumption and allow reaching desired standards of comfort. In a context in which traditional construction systems have still not resolved the social housing deficit in Colombia and which generate high costs for energy consumption in the search for thermal comfort, industrialized and efficient construction with high environmental quality provides solutions according to the economic, geographic, social and cultural context in Colombia.

Key words: Efficiency, industrialization, social housing, sustainability, low energy consumption.

1. Introduction

According to the National Administrative Department of Statistics of Colombia (Departamento Administrativo Nacional de Estadística, DANE), in 2005 the housing shortage in the country reached a proportion of 12.37% of the total households. Currently, the housing deficit in Colombia is close to 1,300,000 units [1]. The Colombian Chamber of Construction (CámaraColombiana de la Construcción, CAMACOL) has recorded an annual increase in the country's social housing deficit of 70,000 units [2]. Added to the problem of the deficit increase, social housing built in warm humid climates has high operating costs due to energy consumption of mechanical equipment used to achieve desired temperatures in interior spaces. This research aims to generate processes of industrialization and qualification of social housing in Colombia through prefabrication, low energy consumption and high environmental quality to reduce the current deficit and improve the quality of life in communities with fewer economic resources.

2. First Point: Deficit Increase

One of the most relevant causes to explain the increase in the deficit of social housing in Colombia is the inefficient use of available resources, which increases the time and construction costs originally proposed. According to DANE, between 1993 and 2005, the housing deficit in Colombia increased by about 460,000 units [1]. In 2012, CAMACOL reported that the country needs 250,000 new homes each year, but only 150,000 are built.

Of this annual deficit of 100,000 units, 70% corresponds to social housing [3]. Additionally, the construction costs of traditional systems, such as reinforced concrete structures cast *in situ* and brick masonry, grow at an annual rate of 6.5% in Colombia,

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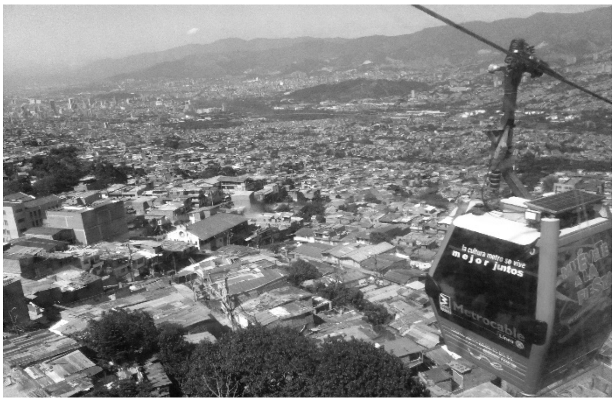

Fig. 1 Informal social housing in Colombia, 2012.

according to research conducted by the Colombian Index of Construction Costs (Índice de Costos de la Construcción, ICC) [4]. These systems are used in 90% of the cases for the construction of social housing in the country (Fig. 1) according to figures provided by CAMACOL [5].

3. Second Point: Operating Costs

In most cases, social housing located in warm humid climates requires the use of mechanical equipment to achieve desired indoor temperatures, which increases energy consumption and operating costs in households of families with limited economic resources.

Colombia is located in a tropical area and its climate has different thermal levels. In warm humid climates, with temperatures between 25 °C and 35 °C, the control of solar incursion, together with generation of natural cross ventilation in interior spaces, is a strategy that optimizes the use of natural resources and eliminates energy consumption to achieve desired levels of thermal comfort.

4. Research Question

How can the efficiency of construction processes be increased while reducing energy consumption and improving the environmental quality of social housing in Colombia?

To answer the research question, the meaning of these three concepts: efficiency, industrialization and social housing, must be defined in the Colombian context.

5. Meaning of Efficiency

In the context of this doctoral research, efficiency is considered as the optimal use of available resources to achieve the desired results [6]. In this investigation desired results are: decrease the country's housing deficit and improve the quality of life of its inhabitants through social housing with high spatial, constructive and environmental quality, eliminate energy consumption to achieve desired temperatures in interior spaces.

The most efficient technical solution to the social housing problem in Colombia will be the optimal uses of available resources in the construction process. The most efficient environmental solution will be the elimination of the energy consumption required to obtain the desired temperatures in interior spaces.

6. Meaning of Industrialization

Industrialization is defined as the set of activities that increase the speed of production and installation of the elements that comprise the projects, usually through standardization [6].

The industrialization processes in this doctoral research refer to precasting concrete, which improves the characteristics of the material and its mechanical behavior, the surface quality and precision assembly. Precast concrete optimizes production processes, and through its mass production, facilitates assembly and installation activities [7].

7. Meaning of Social Housing

According to the Ministry of Environment, Housing and Territorial Development of the Republic of Colombia (Ministerio de Ambiente, Vivienda y Desarrollo Territorial de la República de Colombia), there are two types of regulations for social housing.

7.1 Social Interest Housing

Social Interest Housing (*Vivienda de Interés Social,* VIS), has a maximum cost of 135 minimum monthly wages in Colombia [8], equivalent to approximately 28,700 Euros. The average area of this kind of housing

Fig. 2 Social interest housing in brick and cast concrete.

Fig. 3 Priority social interest housing, interior space.

is between 52 and 60 m^2, which means that the cost of a square meter is between 552 and 478 Euros (Fig. 2).

7.2 Priority Social Interest Housing

Priority Social Interest Housing (Vivienda deInterés Social Prioritario, VIP) is a type of basic housing with lower costs and smaller areas than VIS. This housing has a maximum cost of 70 minimum monthly wages in Colombia [8], approximately 14,900 Euros. The average area of this VIP housing is between 36 and 45 m^2, equivalent to a square meter cost between 414 and 331 Euros (Fig. 3).

8. Responses to the First Point

To reduce the existing deficit of social housing in Colombia, its industrialization is proposed beginning with precasting the concrete, due to the knowledge that exists in the country on the technique of cast concrete *in situ*, a cultural tradition that has used the material in formal and informal construction processes and the availability of raw materials for its production in the country. To decrease the deficit of social housing units in Colombia, it is necessary to increase the efficiency of the construction process through these four activities: design (urban, architectural, technical and environmental), production, transportation and assembly.

Urban design involves the planning of a plot of land available for the construction of housing units. Architectural design seeks efficiency in the use of interior spaces through the principles of dimensional coordination. Technical design includes the shape, number and dimensions of the construction elements; it seeks standardization of parts to generate the greatest amount of shapes with the least number of elements to increase the flexibility and efficiency of installation processes. Environmental design seeks comfort in the interior space through passive cooling strategies, such as control of solar incursion and the generation of natural cross ventilation in the interior space of the houses.

Production considers the cost of materials, labor, machinery, physical space and energy needed for the prefabrication of the housing elements. In production it is possible to standardize parts, reduce time and find more efficient proportions of concrete mixtures to reduce costs. In this activity, four experiments were conducted, in order to reduce production costs and improve efficiency bioclimatic behavior.

The first experiment in the production activity is the decrease in the amount of cement by using industrial byproducts. This activity recycles materials and reduces costs of the mixture. The ash produced by the burning of products in industrial furnaces, the micronized glass, or steel slag powder, reduce the use of cement by up to 18% per cubic meter, while retaining the resistance required by Colombian Earthquake-Resistant Code (Código Colombiano Sismo-Resistente) [9].

In Colombia, cement can cost up to 175 Euros per ton, twice the cost of materials in European countries like Spain and Germany [10]. In addition to the cost benefits for the construction of social housing in Colombia, its reduction would involve the use of residual materials obtained in industrial processes.

A second experiment in the production activity has been the incorporation of lightweight elements. In the research process, polystyrene sheets have been used that reduce the weight of precast concrete by up to 40%, compared to conventional precast concrete elements, while maintaining the resistance required by the Colombian Earthquake-Resistant Code. Incorporating these polystyrene sheets creates conditions of thermal and acoustic insulation, and reduces costs compared to conventional precast concrete by up to 8% per cubic meter. In the research process, we have built walls, slabs and roofs that were installed on a prototype built and exhibited at the XX Version of the International Construction, Architecture and Design Convention *Expocamacol*, held in Medellin from 27th to 30th August, 2012 (Fig. 4).

Each precast concrete piece has a 15-centimeter section and is also formed by reinforcing steel and an expanded polystyrene sheet. This sheet, which has a 10-centimeter section, is placed inside each precast element and functions as lightening and as thermal and acoustic insulation (Fig. 5).

The concrete covering on the entire surface is 2.5 cm thick. Inside, a structure of reinforcing steel provides the necessary resistance to the lightweight precast concrete element (Fig. 6). In the social housing prototype, temperature differences of up to 12 °C were recorded between the outer and inner surface, after 8 h of exposure to sunlight.

The third experiment is the precasting of prestressed alveolar elements, using 35% less concrete by having a geometric shape that replaces the spaces that the mixture should occupy with air, while reducing the weight of steel reinforcements by up to 40% per cubic meter. These alveolar elements have used mixtures with 220 kg of cement and 80 kg of recycled ash per cubic meter, resulting in a further reduction in prices and weights due to the composition of the mixture and the reduction in its volume. By having air chambers in their interior, the alveolar elements (façade walls and slabs) lower the heating of the surfaces and, therefore,

Fig. 4 Prototype built in precast concrete, August 2012.

Fig. 5 Expanded polystyrene sheet with reinforcing steel.

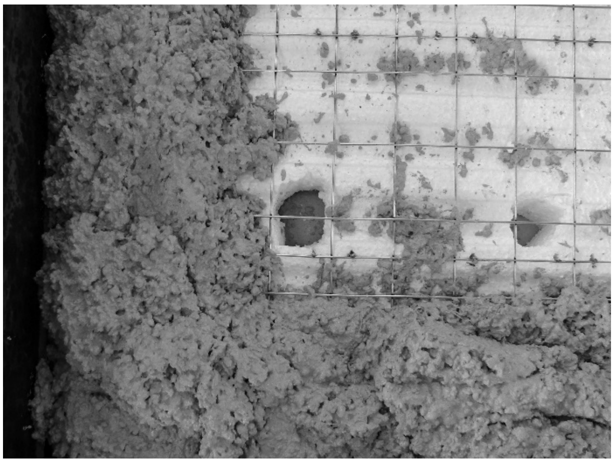

Fig. 6 Concrete coating on expanded polystyrene sheet.

prevent the passage of heat from the exterior to the interior space (Fig. 7). In the same prototype, the temperature difference between the outer and inner surface reached a maximum of 10 °C after 8 h of exposure to sunlight.

The fourth experiment in the production activity was the production of precast concrete elements with textures, which have the ability to auto-shade the material and reduce the heat produced by thermal conduction (Fig. 8). These elements decrease temperatures between the outer and inner surface by up to 7 °C after 8 h of exposure to sunlight.

The proportion of production costs in traditional prefabrication processes ranges between 54% and 60% of the total cost of prefabrication activity (production, transport, installation), which places it as the most costly activity of the process, due to the cost of materials, labor and energy use. With the decrease in mixture costs by using industrial byproducts, recycling of some materials or decreasing the amounts of concrete for the construction of prefabricated elements, production costs have been reduced by up to 12% by cubic meter.

The transport of the precast elements to the construction site is the third activity of the construction process. Its cost is proportional to the distance between the plants and the location of the buildings. In this research, we have analyzed the transport costs in six projects located in the city of Medellín between 2012 and 2013. The cost of transportation between the production plant and the construction site has an incidence of between 11% and 16%, according to information provided by the Precast Concrete Committee of the Colombian Chamber of Construction (Comité de Prefabricados de Concreto de la CámaraColombiana de la Construcción, CPC) [11]. This activity is conditioned by the topography and the accessibility to the project area. It is possible to reduce the transport costs of the precast elements from the production plant to the project and streamline installation processes, if the possibility of including field factories is considered, which are provisional precasting plants that are located at the construction site.

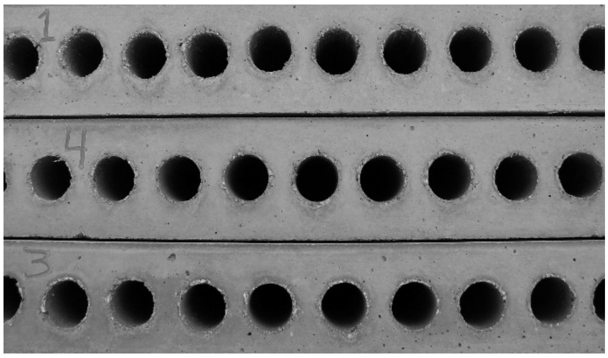

Fig. 7 Prestressed alveolar elements.

Fig. 8 Textured precast concrete elements to auto-shade.

In the installation activities, the assembly between the construction elements must be as simple and safe as possible to reduce time and ensure the proper performance of the parts that make up the building. According to the buildings analyzed and data provided by the CPC, installation costs account for approximately 24% to 35% of the construction cost, making them highly variable and significantly affecting the budget and schedule, if joints and assembly processes have not been foreseen [12].

9. Response to the Second Factor

To eliminate energy consumption caused by mechanical refrigeration systems in social housing in warm humid Colombian climates, passive air-cooling strategies are proposed through the production of materials with low thermal absorption and through the proper use of existing natural resources, such as the sun and wind.

The first strategy is found in the production processes of the precast elements. The use of thermal-insulation materials in the prefabrication of walls, slabs and roofs has a positive impact on this activity. Precast concrete elements with 15-centimeter sections that have a 10-centimeter section of expanded polystyrene sheet in the interior have reduced by up to 12 °C the temperatures between the exterior and interior surface, with 8 h of exposure to sunlight. The 13-centimetre section precast alveolar elements, with interior lightenings of 8 cm in diameter, permitted a maximum decrease in temperature of 10 °C between the outer and inner surface. Textured elements that can be auto-shaded had reductions by up to 7 °C with 8 h of sun exposure in the city of Medellín.

The bioclimatic designs of the social housing complement the use of low-thermal absorption materials and through the use of passive cooling strategies, such as controlling solar incursion and generating natural cross ventilation currents, which permit reaching desired temperatures in the interior space without using mechanical cooling equipment.

To control solar incursion, the question is how to reach the temperatures desired in the interior spaces of social housing and generate naturally illuminated and naturally ventilated spaces with high levels of comfort, without using mechanical equipment. Elements such as decks, balconies or exterior circulations provide shade and allow natural light through the indirect capture of sunlight. These solar-incursion control strategies are studied according to the orientation of each project, with the climate of each city and the hours of shade desired for facades facing the most unfavorable conditions, mainly between 10:00 a.m. and 5:00 p.m. Architectural design must provide the minimum amount of elements to generate the shadows needed in the search for passive cooling in the interior spaces of homes and maintain adequate levels of natural light without direct radiation. Some architectural exercises to implement solar-control elements on the façades of the social housing projects were developed from the modification of the basic unit with which the prototype was built (Figs. 9 and 10).

To generate natural cross ventilation, vents that filter air should be placed on the top and bottom of two façades, perpendicular to the wind direction [13]. To generate wind currents in interiors and maintain the desired temperature levels, it is necessary to define opening ratios between 10% and 15% on each facade, according to the project location and climatic characteristics of the site (Fig. 11).

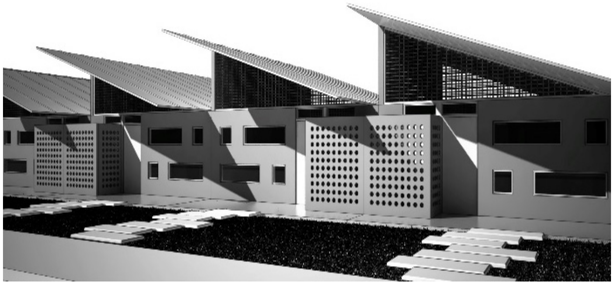

Fig. 9 One- and two-story precast concrete social housing.

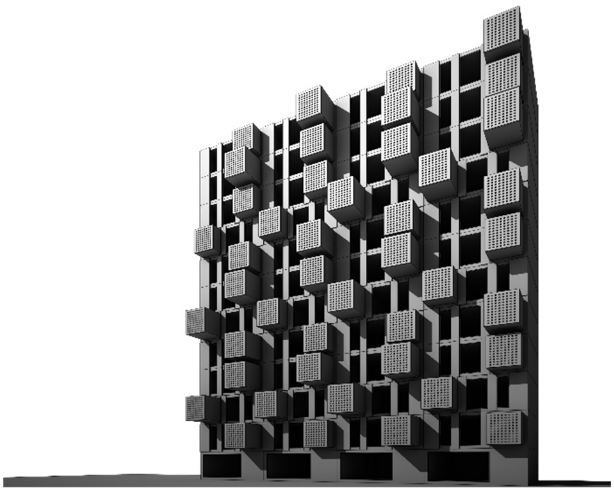

Fig. 10 High-rise precast concrete social housing.

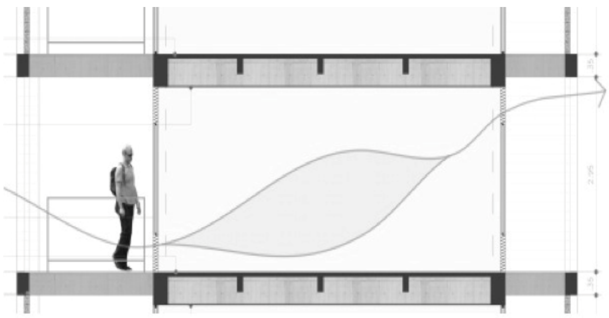

Fig. 11 Natural cross ventilation in the interior space.

Achieving the desired temperatures in warm humid Colombian climate does not require the use of mechanical equipment to achieve the desired levels of comfort in social housing projects, so expenses are reduced for energy consumption while improving the quality of life for families who live there.

10. Conclusion

In response to the gradual increase in the deficit of social housing in Colombia, the optimal use of available resources (space, materials, labor and machinery) allows thinking about achieving the desired results (deficit reduction through the construction of replicable housing with spatial and environmental quality).

In the production process of the precast concrete elements for the design and construction of social housing in Colombia, the use of recycled materials, the use of lightweight materials or the relief of the elements through geometric principles such as alveolar walls and slabs, generate advantages such as improving the environmental conditions, reducing the volume of materials, lowering production costs and improving the environmental quality of the housing.

In response to the issue of the costs of operation and maintenance of social housing in Colombia, passive cooling strategies, such as controlling solar incursion and the generation of natural cross ventilation, reduce operating costs, achieve the desired standards of comfort and improve the quality of life of communities.

In a context in which traditional construction systems have not solved the shortage of social housing in Colombia and which generates high costs for energy consumption to achieve the desired bioclimatic comfort, the efficient construction of spaces with high environmental quality and low energy consumption can provide efficient and economical solutions in relation to the social and cultural context to improve the quality of life of numerous Colombian families.

Author Contribution

In the development of this doctoral research, the author took all the photos.

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