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Design and construction of modular panel prototype replacing unicel with the reuse of cardboard

Diseño y construcción de prototipo de modular panel sustituyendo el unicel por la reutilización del cartón

TREJO-TORRES, Zaira Betzabeth*†, RODRÍGUEZ-URIBE, Juan Carlos and BENITEZ-ALONSO, Margarita

Tecnológico Nacional de México/Instituto Tecnológico Superior de Huichapan, Licenciatura en Arquitectura. Dom. Conocido S/N, El Saucillo, Huichapan Hgo. C.P. 42411. México.

ID 1st Author: *Zaira Betzabeth, Trejo-Torres* / **CVU CONAHCYT ID:** 774137

ID 1st Co-author: *Juan Carlos, Rodríguez-Uribe* / **CVU CONAHCYT ID** 166235

ID 2nd Co-author: *Margarita, Benítez-Alonso* / **CVU CONAHCYT ID** 1249989

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Abstract

Self-construction is a scenario that frequently occurs within the construction field. The purpose of this project is to reduce cardboard waste, giving it a second use and also reduce the cost of construction, mainly in the self-construction field. As a result of an exhaustive investigation about the history of panel and its main component material, which is polystyrene, the environmental impact that its use (polystyrene) represents is considered, which is why the replacement of polystyrene is proposed, for a material that completely reduces or mitigates this contamination problem, taking into account the characteristics of a new recycled material such as cardboard and pointing out the differences and improvements that this material contributes. With this project we demonstrate a construction system that reduces loads within a building.

Self-production, Optimize, Pollution

Resumen

La autoconstrucción es un escenario que frecuentemente se presenta dentro del ámbito constructivo. El propósito de este proyecto es disminuir el desperdicio de cartón, brindándole un segundo uso y además disminuir el costo de obra principalmente en el ámbito autoconstructivo. A raíz de una investigación exhaustiva acerca de la historia de paneles y su material componente principal que es el poliestireno, se considera el impacto ambiental que el uso del mismo (poliestireno) representa, es por ello que se propone la sustitución del poliestireno, por un material que disminuya o mitigue completamente este problema de contaminación, tomando en cuenta las características de un nuevo material reciclado como lo es el cartón y puntualizando las diferencias y mejoras con las que contribuye este material. Con este proyecto demostramos un sistema constructivo que disminuye las cargas dentro de una edificación.

Autoproducción, Optimizar, Contaminación

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* Author's Correspondence (E-mail: ztrejo@iteshu.edu.mx)

† Researcher contributing as first author.

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Introduction

Nowadays, self-build is a scenario that can be seen almost everywhere you look. In Mexico, self-construction is the main way of producing the city.

This way of producing the city, most of the time, is done with traditional construction methods such as confined masonry walls. Within architecture there are several construction systems, however, they are still not as widely used or even known. Mainly in places where self-building predominates alongside traditional construction systems.

The panel is a construction element that has begun to be implemented as a solution to divide spaces in different buildings, all thanks to its ease of installation and the time required to put it into service, although it is considered that there are some aspects in which the panel could obtain improvements, such as lightness, cost and exchange of unicel for a more ecological material, from a recycled material, easy to handle and that supports self-construction. The degradation time of some materials, such as polystyrene, is too long, according to (UNAM, 2018) it takes between 500 and 800 years to degrade.

As a result of an exhaustive research about the history of the panel and its main component material which is polystyrene, the environmental impact that the use of the same (polystyrene) represents is considered, which is why the substitution of polystyrene by a material that reduces or completely mitigates this pollution problem is proposed, taking into account the characteristics of a new recycled material such as cardboard and pointing out the differences and improvements with which this material contributes, not only to the reduction of pollution produced in construction works, but also to the optimisation of resources and structural improvements such as lightness.

The discovery of expanded polystyrene was made in 1831 with a colourless (transparent) liquid, styrene, which was first obtained from the bark of a tree. Today it is mostly obtained from petroleum.

Polystyrene began to be manufactured in 1930 and towards the end of the 1950s, the German company BASF, on the initiative of Dr. F. Stastny, developed and started production of a new product: expanded polystyrene, under the brand name Styropor. That same year it was used as an insulator in a building within the same BASF plant where the discovery was made. (López & Canepa, 2013).

The material was also considered an excellent product due to its various thermal and mechanical properties. Another point in favour of this product is the ease and simplicity of production (Ruiz et al, 2019).

For some authors, consumerism and overpopulation are the 2 essential causes of the environmental problems we are experiencing today.

With the development of industry, production processes have accelerated, bringing with them two phenomena: the generation of greater volumes of waste and excessive consumption of the goods produced, together with their packaging.

Considering the above, we can say that all citizens are potentially responsible for both the use of resources and the generation of waste.

According to the SEDEMA, packaging has increased the personal production of waste in recent decades, occupying between 30 and 35% of daily waste production. In Mexico, in 2012, approximately 37.5 million tonnes of waste were generated annually; in the last ten years, total MSW generation has increased by 26% (Alma Liriet Álvarez, 2017).

The problem extends to the great waste of paper and cardboard in Mexico, as it mentions (INEGI, 2020), that in 2020 2.8 million tonnes of cardboard were produced where most of it is not recycled and/or ends up in inappropriate places such as natural habitats, sewers, etc.

The cost of the polystyrene w-panel combined with the labour required for its assembly is somewhat high, therefore, in particular cases such as self-construction it is not taken into account.

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The implementation of recycled materials as substitutes for polystyrene is crucial, resulting in a significant decrease in environmental impact. According to the World Bank (2018), Mexico is currently facing a serious environmental problem as it is the third largest rubbish generator in the world and the first among Latin American countries. This project not only seeks to reduce environmental pollution, but also aims to boost the implementation of low-cost panels that are lighter in weight compared to traditional methods such as block walls. It is intended that the scope of the panel is achieved even in low-income areas and can be implemented in self-build projects, due to its simple manufacture and ease of transport and assembly.

The construction sector is a major contributor to economic growth. The investment-driven sector improves the country's long-term competitiveness and affects the quality of life of citizens.

As a result, construction spending worldwide reached more than USD 11 trillion in 2019.

Advanced countries have recently promoted Integrated Modular Construction (MiC) as an effective solution to:

1.- Enable faster construction.

Improve the declining productivity of construction.

2.- Support sustainable development.

In response to the COVID-19 pandemic, the completion of a 1,000-bed MiC-based hospital in Wuhan, China, in less than a month, has got the world, especially sophisticated economies, "talking" about this new technology. (Chan Tsz Wai, 2023).

The five pillars of sustainable architecture

In order to identify the indicators that should regulate the degree of sustainability of a building, one should first start by identifying the general objectives that must be achieved in order to achieve a comprehensively sustainable architecture.

These objectives constitute, therefore, in Figure 1 we can observe the basic pillars on which sustainable architecture should be based (Garrido, 2014).

Pillars of sustainable architecture

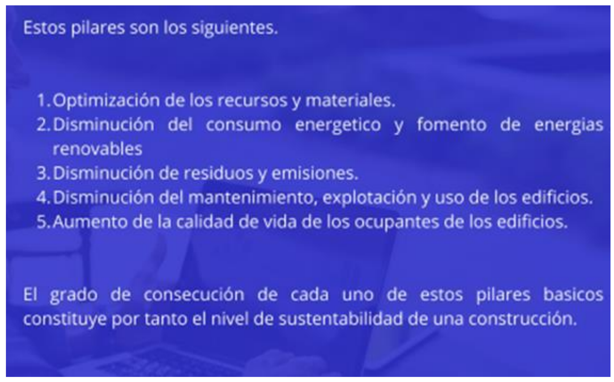

Figure 1 The image shows the five pillars of sustainable architecture by Luis de Garrido
Source: Garrido, 2014

Waste in Mexico

Urban solid waste:

As mentioned, (Ochoa,2010) the management of urban solid waste (USW) in Mexico represents a problem due to several factors, such as lack of basic information, limited economic resources to explore adequate waste treatment systems and technologies and insufficient waste collection, among others, who cites (Comisión Mexicana de Infraestructura Ambiental 2003).

An example is Mexico City, where according to (INEGI, 2020) its population is 9,209,944 inhabitants, where according to a 2004 study the Ministries of Works and Services and Environment announced that the Federal District produces 12 thousand tons of waste per day, an average of 1.5 kilograms per person of waste every 24 hours. (Reyes, 2004).

It indicates that Mexico City recycles barely six percent of the 12,000 tons of waste produced per day. This gives a total of 720 tonnes recovered per day, as shown in Figure 2. (Vázquez, 2011)

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Figure 2 Graph of waste recycling in Mexico City
Source: Vázquez, 2011)

Construction waste:

The continuous growth of cities also brings with it the growth of the construction industry to build the infrastructure that makes it possible for its inhabitants to carry out their activities. This industry generates a large amount of waste, known as construction and demolition waste (CDW), which, if improperly managed, can cause problems that affect the environment, reducing the quality of soil, air and water (Rivera, 2008).

Previous designs

According to Avilés and Nieblas, a structural element such as a wall functions to support load and transmit it to the foundation. According to Avilés and Nieblas, a load-bearing or structural wall is any element that supports compressive, bending, shear, flexural and torsional stresses, derived from gravity loads (dead load and live load), as well as accidental loads (wind and seismic), whether they are made of masonry or any other material. A lightweight wall is any construction element that is composed of materials with physical properties such as low density, reduced thickness, great slenderness, easy handling and installation (Avilés & Nieblas, 2001).

It is a light, insulating and rigid construction element, basically composed of an expanded polystyrene plate reinforced throughout its body by a three-dimensional structure of high-strength steel wire, this reinforcement consists of electro-welded mesh on both sides of the panel joined by a series of perpendicular zig-zag ladders placed at the same spacing, thus forming a three-dimensional structure, as shown in Figure 3 and 4 is a clear example of a structural panel wall. (Avilés & Nieblas, 2001

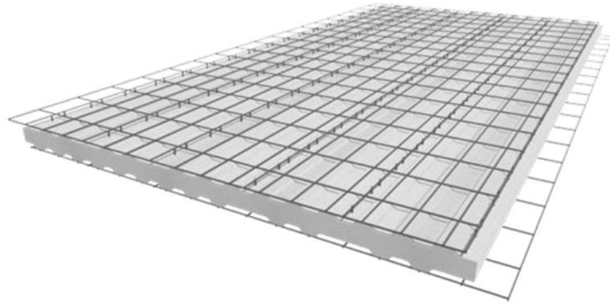

Figure 3 Expanded polystyrene panel wall reinforced with high-strength steel wire tridistructure
Source: Steel Technical Manual), cited by (Avilés & Nieblas, 2001

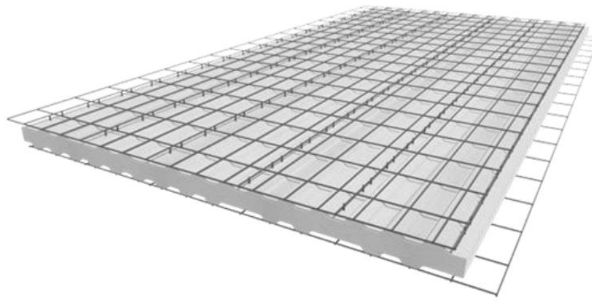

Figure 4 Expanded polystyrene partition panel reinforced with steel wire tridistructure, does not withstand load stresses
Source: Steel technical manual) cited by (Avilés & Nieblas, 2001

Methodology to be developed

Reduction of cardboard waste.

The main material to be used is the leftover cardboard from a packaging company located in Huichapan, Hidalgo. According to (Carlos, 2022) the company consumes approximately 35,000 m2 of cardboard, of which three to five percent of the cardboard becomes waste as shown in Figure 5.

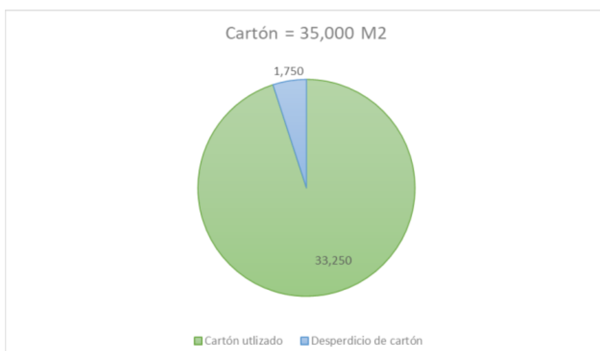

Figure 5 Graph of cardboard waste by packaging company
Source: own authorship, 2022

It is estimated that making a modular panel measuring one point twenty-two metres wide by two points forty-four metres high would give a total of two points ninety-seven, where for each Modular Panel, zero point sixteen percent of the surplus cardboard would be recycled, as shown in Figure 6, which is produced by the packaging company.

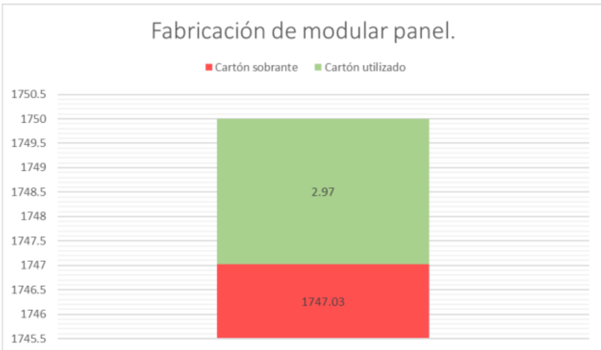

Figure 6 Cardboard recycling graph for each Modular Panel
Source: own authorship, 2022

Design and prototyping integrating plans and 3D modelling.

Design

Taking into consideration that we have all the theoretical foundations, we proceed with pencil and paper to draw some sketches where taking into account the average height of the house in Mexico according to the bibliography of "Barefoot Architect 2020" says that the average height is two point five meters, that is why in the design we contemplate the height of the panel of this measure taking into account that the thickness of the average walls in Mexico is 15 cm in the panel is proposed 10 cm which can be seen in Figure 7.

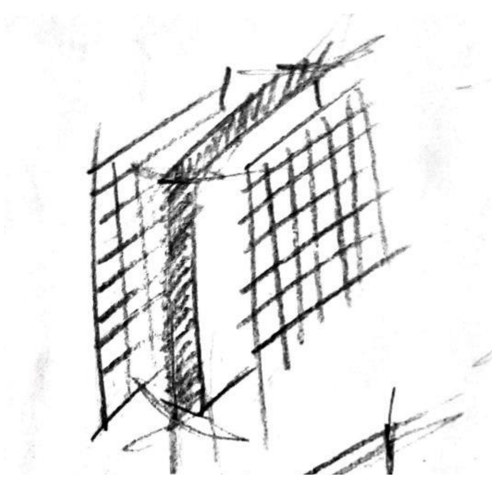

Figure 7 Main idea of the Modular panel
Source: own authorship, 2022

As part of the process, new ideas are given and the design is complemented as shown in Figure 8.

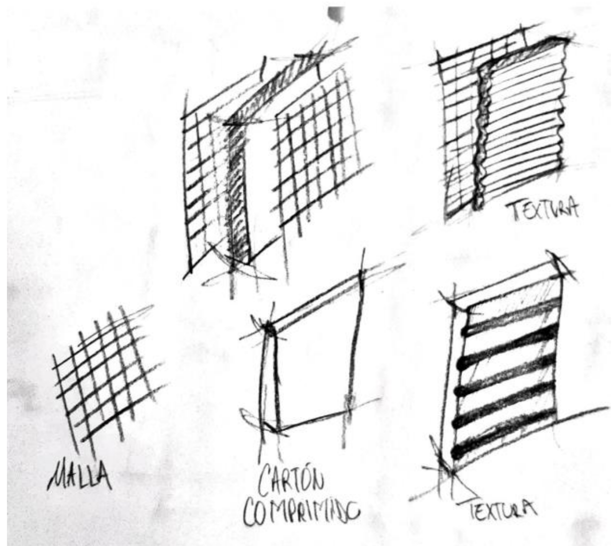

Figure 8 Ideas of the characteristics of the Modular panel, as well as each of its parts, in the design part a texture is implemented in the cardboard
Source: own authorship, 2022

The Modular panel is modelled in a 3D design programme according to the measurements mentioned in Figure 9.

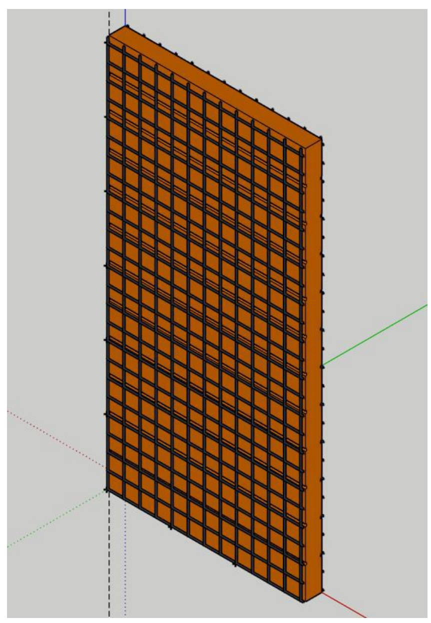

Figure 9 The image above shows the final design from a 3D design program
Source: own authorship, 2022

Subsequently, an isometric view of the development of the Modular Panel is worked on, as shown in Figure 10.

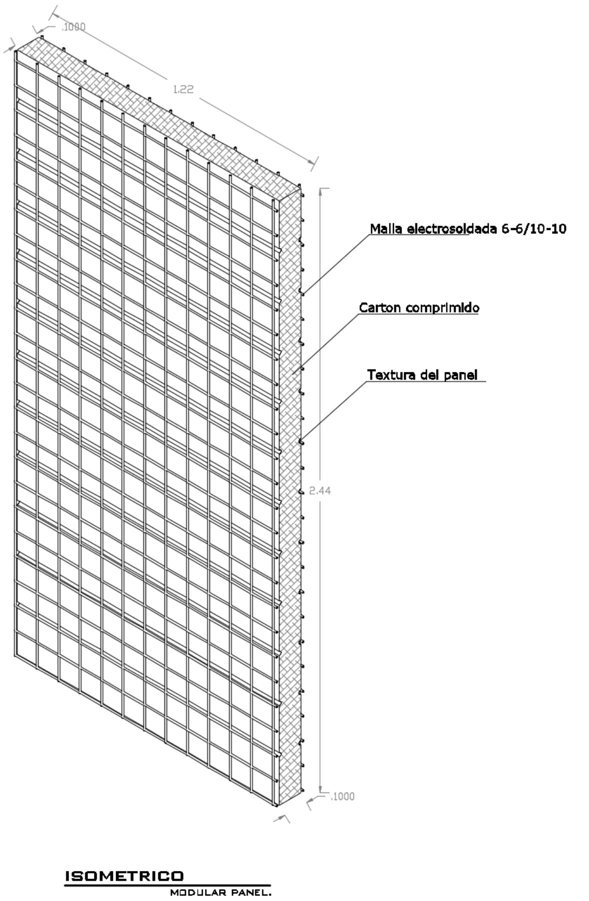

Figure 10 A view of the Modular Panel is shown, as well as measurements and specifications
Source: own authorship, 2022

Results

In the first instance, for the development of the modular panel, the main raw material, which is cardboard, was sought to be recycled or obtained from cardboard remnants that were not useful for any other activity than recycling.

A visit was made to a donor site looking for raw material in good condition from leftovers as shown in Figure 11. The engineer in charge of the site was allowed to explain the process that takes place within the facility. He explained how cardboard waste is generated, as well as the exact quantities that are considered waste as shown in Figure 12.

Figure 11 We visited a cartonera where the die-cutting phase is carried out in search of cardboard waste
Source: own authorship, 2022

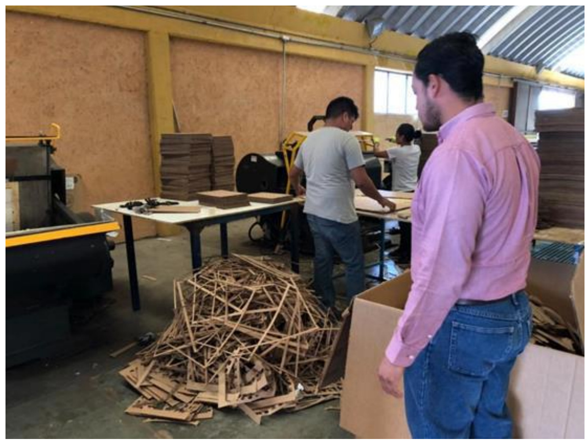

Figure 12 Optimal cardboard waste is obtained for recycling in the Modular Panel prototype
Source: own authorship, 2022

Once the material was obtained, it was concluded that although the waste was smaller than a cardboard plate, the waste still had a considerable size to be able to handle the material, which is why a further process was carried out to obtain smaller pieces of cardboard as shown in Figure 13.

Figure 13 Small pieces of cardboard were made from the strips of cardboard produced by die-cutting, making sure that they were no larger than 5 cm
Source: own authorship, 2022

Now, having the cardboard ready for mixing, the next step is to make a mould that provides the desired texture for the panel, as shown in Figure 14.

Figure 14 Construction of the mould, the texture seeks a good performance in the face of the plaster
Source: own authorship, 2022

Once the mould is made, the mixing of the ground cardboard and Resistol 950 is started, see Figure 15.

Figure 15 Mixing of cardboard with Resistol 950. The mixture is mixed little by little to make it more homogeneous
Source: author's own work, 2022

The mixture made by shredding the cardboard and Resistol is then placed inside the mould, which is left to dry for three days as shown in Figure 15.

Figure 16 Placing the mixture inside the mould
Source: own authorship, 2022

Once the drying process is complete, the mould is removed as shown in Figure 16.

Figure 17 With the help of a spoon, the mould can be removed from the cardboard plate
Source: own authorship, 2022

Cost analysis

As part of the methodology, a cost analysis was carried out using the programme (Microsoft Excel, 2019) where the result was very positive compared to traditional systems (masonry), as shown in Figure 17. Since the saving is quite a lot compared to the Modular panel, it is therefore advisable to use it in self-construction in Mexico, for its great importance on the reuse of cardboard, as well as giving a new use to cardboard, which is why with this analysis we could realize that the cost decreased by 32% having as cost in the traditional system (masonry) per module of three meters by two points five meters in height a cost of $14,195. In comparison with the Modular Panel with a cost per module of $9,630.

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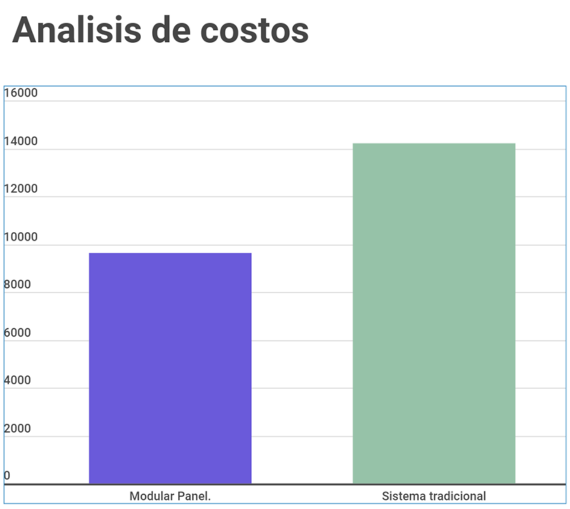

Figure 18 The graph shows the costs of the two construction systems
Source: own authorship, 2022

Prototype construction

As indicated in the methodology, the construction of the designed panel is carried out. This panel complies with expected characteristics such as lightness, lower cost than other systems and also its construction process promotes the reuse of cardboard. The prototype proposes a way of building that is friendly to the natural environment, as shown in Figure 18.

Figure 19 The different layers of the panel can be seen. The first layer or core is compressed cardboard, the second layer is mesh and finally there is the gypsum sheathing
Source, own authorship, 2022

The Modular Panel is designed so that the panels are joined together by means of the mesh, i.e. the mesh of one panel can be joined to the mesh of another panel, as shown in Figure 19.

Figure 20 The figure shows the mesh that not only acts structurally, but also as a connection between panels
Source, own authorship, 2022

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Conclusions

Once the previous studies of the present project have been carried out, we have the necessary and sufficient information that allows us to reach the following conclusion:

Derived from this research, the development of a Modular Panel is obtained, which favours in the process of self-construction and allows the development of the same in a minimum time derived from the fact that it is considered a non-structural panel, taking the function of dividing panel.

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We were able to observe that the reuse of cardboard is of utmost importance since there are companies that are dedicated to the development of cardboard-based packaging and that the waste they generate is practically discarded.

We also consider that the thermal conditions offered by the Modular Panel are favourable for climates with low temperatures.

We also determined the cost, which is reduced by 32% compared to existing traditional systems.

Finally, it can be said that this Panel favours the development towards a sustainable and sustainable architecture.

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