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Original Research Article

Ecological building material in glass, sand and polyplastics (vapoli)*

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ABSTRACT: This article refers to the development of a new environmentally friendly construction material; it mentions concepts of contamination in Colombia where the lack of reuse of recyclable materials is demonstrated with figures, and states its objectives and justification according to the needs or deficiencies outlined in the document. In the research, studies of similar models are carried out where research related to the proposed topic is shown; likewise, articles and national and international laws that support this work are evoked.

KEYWORDS: Pollution; Ecological; Ecosystems; Plastics; Toxicity; Constructive; Toxicity

Introduction

This article is defined within the framework of the call for Internal Projects Research Groups, young researchers, undergraduate work Faculty of Architecture, Universidad del Atlántico, Resolution 001025 of July 2019. The article is framed within the lines of New Knowledge Management, Innovation, Technology and Creativity, in the area of construction and design, as well as in the search for new materiality with sustainability conditions, developed in the Faculty of Architecture, Universidad del Atlántico.

The methodological aspect is presented, where the type of research carried out during the entire project is presented: research design, research approach, methodological design where its phases and respective stages are described; techniques, instruments and equipment used, with their respective technical data sheet. It also describes the materials selected for the tests and their classification by toxicity levels. The procedures used for the material in the test tubes are described, such as: starting and ending time, weight of the material, photographs, among others. Finally, the analysis and interpretation of results obtained from compression and flexural tests, among others, are presented. A comparative table between bricks, conventional blocks and the ecological brick proposed in this document is also presented. Finally, the architectural construction proposal for both brick and columns and different components that will complement the use of this construction system are shown; in addition, its application and manageability in different situations and scenarios are described.

Environmentally friendly products

Relevance of environmentally friendly products

Currently, one of the biggest problems facing the planet is related to the millions of tons of plastic waste produced in the sea, disturbing its fauna and flora. This is how plastic islands are beginning to be created, affecting the marine ecosystem. In Colombia, pollution from the uncontrolled use of plastics affects sectors such as: streets, streams, lakes, lagoons, seas, producing a change in its balance and functioning.

Studies conducted by the Colombian Ministry of Environment reveal that landfills have a limit of use, very close to reach; that is why projects and / or companies have been created in order to help mitigate this environmental problem. Considering the above, in this project we proceeded to implement the use of recycled plastics as raw material, in order to obtain a product or material that can be used in various fields of construction. For this purpose, several studies of the proposed material were carried out in order to obtain behavioral variables in the application of different mechanical forces.

Use of recyclable elements in the production of new materials for construction and related areas.

Studies by National Geographic[1] reveal what is currently happening with waste, showing specifically that globally about five thousand seven hundred (5,700) million tons of plastic waste are not properly treated. In addition, around eight million tons of this waste reaches the sea. Maintaining increasing levels of plastic production, without reusing what we already have, implies the enormous possibility of continuing to live with uncertainties about the problem of global warming, making it important to focus interest in seeking universal solutions. Thus, this research work presents a proposal for new alternatives in the reuse of plastic material.

Therefore, it is proposed the development of a new product for construction from the reuse of materials such as plastics and other products. Similarly, this project focuses its search to promote new alternatives with construction materials that help to develop new routes in architecture. Likewise, the basic idea has been to work permanently and progressively, using this material to minimize the amount of plastic waste in order to contribute to the preservation and conservation of planet earth, the only habitable planet we have so far.

At the national level, the Colombian Ministry of Environment executed a study in the population, where it was determined that the country generates "11.6 million tons of garbage"[2], of which the department of Atlántico contributes "2,044 tons/day"[3], in the entire jurisdiction. However, the Mayor's Office of Barranquilla started in 2016 a program called "Green Barranquilla" Barranquilla District Environmental Recoverers Network. An interview was conducted with one of the beneficiaries of the project, Mrs. Diana Hernandez Pertuz, where it was evidenced that the mayor's office made an alliance with plastic and other materials collectors, in order to encourage associations that sell recyclable items reducing waste rates in the city.

There are projects that work to promote positive effects on the environment, being recognized locally and nationally and strengthened with socialization and awareness-raising in the communities. Thus, this project seeks to design construction elements from the reuse of plastic and other materials. This process is considered innovative, not only because of the content of the material, but also because it is light, flexible and versatile. In other words, once the process is done with the material, it is possible to create different useful objects to satisfy basic habitability needs in the communities.

Collaborative approaches for the creation of products from recyclable materials

The environmental problems generated by plastics have a daily impact on the lives of human beings, which has led experts to point out that "part of this waste is already entering the human food chain"[4]. Likewise, another study carried out by the Colombian National Planning Department (dnp) determined that "the useful life of landfills in 321 municipalities in Colombia will end in five years"[3].

In other words, landfills are almost full and the excessive use of plastic has created an over-production of objects and materials that currently take years to disintegrate. The innovative proposal of this project aims to contribute, for the construction sector, with an environmentally friendly material. To this end, the following question is posed: what actions and materials are necessary to mitigate environmental problems in the local, regional, national and international context? The basic idea has been to propose an ecological material with elements of recyclable plastics and other materials for construction processes in general. It was also considered necessary to: 1) identify environmentally friendly construction elements, in order to know their applicability in different construction processes; 2) analyze different construction components through a study, taking into account the characteristics and construction processes, and 3) propose an ecological, resistant and suitable material for the application of the Colombian Seismic Resistant Norm NSR-10.

Collaborative notes for the production of new environmentally friendly elements

All the constructions carried out generate an impact on the environment, since part of the natural resources are implemented in this industry, as explained by Francisco Arenas, doctor in law and technical architect of the Universidad Nacional de Educación a Distancia (National University of Distance Education), when he expresses:

> While it is true that the processing of raw materials and the manufacture of materials generate high energy and environmental costs, it is no less true that experience has shown that it is not easy to change the current system of construction and the irrational use of natural resources, where the priorities of recycling, reuse and recovery of materials are conspicuous by their absence compared to the traditional trend of extraction of natural materials[5, para. 10].

This recyclable material project, whose focus is directed to the construction with environmental lines, has a purpose beyond the creation of the product: it seeks to contribute to society, encouraging the alternative use of new elements for construction, by promoting the reuse of discarded materials. Among the positive effects of the project that should be taken into account, we can count the reduction of plastic waste in the city of Barranquilla and the awareness of recycling.

With the proposed material, it is intended to be part of the proposals in the manufacture of houses and other types of buildings, with low costs and shortening the construction time. This experimental research project brings benefits in terms of costs and budgets, providing the opportunity to offer accessible materials to a community with basic needs. According to studies of similar models and methods, this proposal does not require the use of additional material for its location and handling. The union of some pieces with others can be done in a simple way, as well as the assembly of a wall, which considerably reduces the total cost of the work.

Currently, the cost of building a house using traditional materials has increased by 2.6%. Likewise, within the offers, variations below the average were found related to materials (2.29%), machinery and equipment (1.39%) of high cost, meaning that the lower the impact of construction costs and other variables, the better the market will perform.

The proposal counts on the use of plastic and other recyclable elements that, according to the ecological page Econoticias.com, need at least four hundred and fifty (450) years to degrade[6]. One of the proposals will be the brick, with an assembly method similar to the Lego-type chips, which offers an easy assembly system.

Historically, houses have been built with materials such as cement, lime, plaster, among others. But nowadays, with its evolution and the support of technology, new materials have been created and implemented, following different bioconstruction criteria such as those presented by J. Van Lengen, to avoid environmental deterioration, either by extraction, manufacture, installation or use[7].

The construction group is involved in one third of the world's energy consumption, due to its habitability process and the use of buildings.

The same is true for 17% of drinking water[8], 10% of land[9] and 25% of cultivated wood[8], a value that rises to 70% if all wood resources are considered[10].

At the national level, innovative projects have been developed in the construction area, such as the case of Kolor's ecological paint, formulated with vinyl acrylic resin, high quality additives for greater durability and pigments for greater light fastness and color stability. Another environmental project is that of Conceptos Plásticos, a company that produces ecological blocks based on recyclable plastic.

With studies carried out on construction materials, ecological bricks have been developed in different parts of the world. One of the materials used in these products are recycled plastics, which are abundant and slow to degrade; likewise, information continues to be collected on plastics as a commodity and their use in the construction sector, both nationally and internationally.

The Ecomat Brick, developed in Bergamo, Italy, is a building material that works like Lego pieces, made from recycled plastic from landfills. With these bricks, walls can be built quickly and easily, they do not require mortar or special knowledge, they also have excellent seismic-resistance properties and superior fire resistance, they weigh little, and they are good insulators of noise and temperature[12].

The bricks are manufactured with machinery that produces high temperatures. These ovens melt the plastic for subsequent pouring into specialized molds. These bricks have two standard sizes, the first prototype measures 8 cm × 25 cm × 33 cm, with a weight of 1.49 kg, and the second measures 16 cm × 25 cm × 33 cm, with a weight of 3.35 kg.

The Ecomat building system allows any type of building the possibility of real savings in the realization and installation of the walls and in the management of the construction site, compared to traditional building systems[12].

Bricks made from household plastic waste were handcrafted. Inside a pet (polyethylene terephthalate) bottle, such as those used for soft drinks or water, rubber, sand or plastics are introduced until it is full. Its weight is not standard, since it can vary according to the material used for the filling. For the construction of these eco-bricks, it is not necessary to use a kiln, but another type of construction mechanism is used.

The handmade bricks are compacted with a rigid material, which makes it difficult for them to have the necessary severity to not yield when used in construction. However, the exact values of resistance, speed and other variables are still under study[13].

Eco-bricks have been used in various contexts, taking into account that in the construction of houses their placement time is 20 days, specifically for a standard house of 38 mt2. In 2015, "10 houses with particular characteristics and a multifunctional classroom were built in a school in Pico del Monte, Bolivia"[14]. Its construction system is different from that of lego-type blocks or bricks, since at the time of construction, one container is placed next to the other and joined with cement.

There are also recycled plastic bricks developed in Cali, Colombia. This type of brick is made of recycled plastic; its design allows it to be assembled on site and minimizes construction time to only five days. The bricks are made using plastic from garbage. This plastic,

through an extrusion process, is melted and poured into a final mold, creating a brick weighing three kilos (...). With a final cost of 20 million Colombian pesos per housing unit, the company builds in five days and with four people a 40 square meter house with two bedrooms, living room, dining room, bathroom and kitchen[15, para.4-5].

The material is made with high temperature machinery to melt the plastic, the bricks measure 50 cm x 7 cm x 13 cm and weigh 3kg. Its union does not need glue because it uses a lego type assembly system.

HomeCell bricks can be found in Cali, Colombia. These bricks are composed of 50% polymer, a waste product of industrial activity, and the other 50% "by natural waste such as rice husks, coffee husks, and elements such as uv protective dyes to avoid the impact of the sun's rays (...). Each square meter built with HomeCell modular blocks costs $ 650,000" Colombian pesos[16].

To make these bricks, high temperature machinery is used to melt the plastic. The size of each brick is 10 cm × 10 cm × 20 cm; its construction system is lego type, it does not need additives to join them. Currently there is a house built with this construction system, located in the town of Pance in Cali. "Two projects for strata 5 and 6 are currently being developed in the Lake Calima dam, located in the municipality of Calima El Darien" [16, para. 16].

Evolution of construction materials

In ancient times, the predominant materials used in construction were stone and clay bricks, among others. These materials evolved, and nowadays other construction proposals are being presented in the cities. Currently, construction has become an indicator of economic development worldwide; therefore, the materials used in buildings have been developing in such a way that today we build with light but resistant materials, as is the case of prefabricated materials.

According to the Centro Urbano website, materials are divided into three main categories: the first category are metallic materials, for example, nickel, iron, copper, aluminum and titanium; the second category are ceramic materials, where we find bricks, glass, insulators and abrasives; finally, we have polymeric materials, such as rubber, plastics and other types of adhesives[17]. The following are some of the most commonly used materials in construction today: stone, sand, cement, plastic and glass.

Stone

It is one of the most common and used materials of the earth. Its use in construction has been present in all stages of civilization, since prehistoric times it began to be used without carving for the elaboration of houses, walls, among others. Stones are considered a stone material and can be found in any size. These materials have been used for the construction of pyramids, aqueducts, temples, among others.

The most used stones or rocks have been: granite, slate and marble. According to the website Construmática, this material used for construction has been losing importance due to materials such as concrete and steel, which require more time for its execution[18].

Sand

Sand, like stone, is one of the most widely used materials in construction. It has been present in all stages of civilization. Sand is known as a material whose particle size varies between 0.063 and 2 millimeters[19]. It is used in concrete mixtures according to the requirements of use: for example, S1, S2, S3, P1 and C2; where S is the sulfate resistance, P is the permeability and C is the corrosion resistance[52, C4.2.1]. It is also one of the most abundant on the planet and, due to its characteristics, it can be easily compressed and used to reinforce structures.

According to the magazine ARQHYS. Arquitectura, the granulometry of sands is classified into coarse, medium and fine sands. Coarse sands are those that pass through a 5 mm mesh, but are retained by a 2 mm mesh; medium sands pass through a 2 mm mesh and are retained by another 0.5 mm mesh; fine sands pass through a 0.5 mm mesh, but are retained by a 0.2 mm mesh[20].

Cement

Today, cement is one of the main building materials used for housing, buildings, and bridges. According to studies conducted by the Spanish Institute of Cement and its Applications (ieca), cement originated around 1,600 B.C., as the result of a mixture of limestone, water, sand and aggregates. This new material could be molded while it was still wet, since it hardened when it dried, and its characteristics were remarkable strength and resistance[21].

The creation of cement also gave rise to what is known today as concrete. Today, cement is present in almost every building in the world. A concept of the evolution of cement, found on the website Arquigráfico, states that cement arises from the grinding or crushing of some cementitious stones and changes when in England in 1824 portland cement was created, which is produced from the combination of limestone and clay. Currently, portland cement is expanding its use, as some call it the improved version of traditional cement[37].

Plastic

The first plastic originated in 1860 by Phelan and Collander, who offered a $10,000 reward to anyone who could find an acceptable substitute for natural ivory. American inventor Wesley Hyatt, the first inventor of plastic celluloid (2009), was the one who developed "a method of pressure processing pyroxylin, a low-nitration cellulose nitrate pretreated with camphor and a minimal amount of alcohol solvent" [22, para. 1].

The celluloid developed by Wesley was used to manufacture objects such as knife handles, lens frames and cinematographic films. In the 1930s, English chemists discovered that ethylene gas acted under the action of heat and pressure, forming a material they called polyethylene (pe), while polystyrene (ps) was also developed in Germany during the same years. Also in the 1930s, the chemist Walace Carothers created the first artificial fiber, nylon. In the 1950s, polypropylene (pp) appeared[22]. After World War II, many chemists began to develop new types of plastics.

> Plastic is used in many building products from glues and resins to boards or windows, and once the building is constructed, plastic is also used as a base element for various complements or decorative objects inside our homes[23, para. 2].

Likewise, there are currently a variety of plastic products, but the main application in construction is pipes and ducts for transporting not only water but also gas, effluents and other types of fluids, as well as for cable insulation and restoration. In this case, plastic pipes replace galvanized pipes, since they have fewer failures, are easier to handle and do not suffer from corrosion or sedimentation problems[24, para. 2-3].

> Plastic in general is a material formed by molecules called macromolecules. The concept originates from the fact that these giant molecules "are formed by reactions in which many units of other small molecules (monomers) are joined together to form long chains (polymers)"[25, para. 1]. As shown in Figure 1, the molecular reactions to this process are called polymerization.

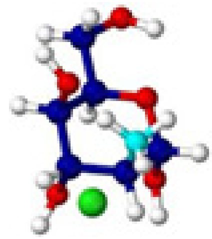

Figure 1. Synthetic macromolecules.
Source: [11].

Types of plastics

Generally speaking, there are two main types of plastics, thermoplastics and thermosets. On the one hand, thermoplastics

> do not undergo changes in their chemical structure during heating. They can be heated and remolded as many times as desired. For example, polyethylene (pe), polypropylene (pp), polystyrene (ps), expanded polystyrene (eps), polyvinyl chloride (pvc), polyethylene glycol terephthalate (pet), among others[26, para. 2].

On the other hand, there are thermosets that "undergo a chemical change when molded and, once transformed by the action of heat, can no longer change their shape. For example, epoxy resins, phenolic and amino resins and polyurethanes"[26, para. 2].

Currently, with the passage of time and scientific evolution, new polymeric materials such as bioplastics, elastomers, biodegradable plastics, polyolefins, engineering plastics, among others, have been developed[27].

Glass

Glass is a crystalline material that melts at high temperature. Its beginnings date back to ancient times, when it was used for costume jewelry. Also, this material was mixed with different minerals to obtain a variety of colors. "The manufacture of glass flourished in Egypt and Mesopotamia until 1200 BC, then ceased almost completely for several centuries. Egypt produced a clear glass, containing pure silica; it was colored blue and green" [28, para. 1].

Over the years, glass began to be used in Gothic cathedrals; its manufacture was revolutionized by a method devised by the French chemist Nicolas Leblanc. From that moment on,

> high quality glass began to be manufactured for use in optical instruments; at the same time, its application became popular, giving birth to objects of common use such as glasses, mirrors, bottles, chandeliers, and other utensils, which provided humans with an improvement in their quality of life[29, para. 6].

Glass becomes a material in constant evolution due to its transformation capabilities, becoming a necessary element in any construction. "It is the most used material to illuminate any type of room"[30, p. 119]. Glass in construction has several applications, such as: safety glass, uv-treated glass, anti-acoustic glass, opaque glass, anti-reflective glass, among others.

Glass is an "amorphous material produced by the fusion of silica and additives at very high temperatures"[31]. It is considered amorphous because it is neither liquid nor solid, being in a glassy state, where its molecular units have excellent mechanical rigidity. Glass can be classified according to its chemical composition into: a) soda-lime glass, used for containers or windows; b) leaded glass, used for polishing and surface decoration carvings; c) borosilicate glass, used for laboratory utensils, and d) special glasses, composed of various chemicals according to their use.

The glass used in this proposal is soda-lime glass, since according to a document issued by the Chamber of Flat Glass and its manufactures of Argentina[31] it is the "most common and least expensive". This material is found in bottles, jugs, glasses for daily use, among others. In order to go deeper into this, some results of two studies made on this material will be presented below.

Test "Influence of the incorporation of crushed glass on the properties and high-temperature behavior of cement mortars"[32].

This trial was conducted by Vicente Flores-Alés and Víctor Jiménez-Bayarri, professionals from the University of Seville, Spain, and Alexis Pérez-Fargallo, from the Universidad del Bio-Bio in Concepción, Chile. The article was published in the Boletín de la Sociedad Española de Cerámica y Vidrio, March 2018. It deals with the incorporation of glasses to cement mortars, presenting a high degree of recovery and reuse. Its main objective has been to check the behavior that the cement has, when the aggregate is partially replaced.

Likewise, in the article presented, the measurements of reference mortar 1:3 (cement / sand) with proportions of 25% cement and 50% sand in relation to weight are worked. Thus, "significant differences in the samples are deduced, which are reflected in a better behavior for the materials that incorporate glass fractions in their composition"[32, p. 257].

Testing of recycled plastic granules and demolition waste as construction materials

This trial was conducted by Arul Arulrajah and Ehsan Yaghoubi, members of the Department of Civil and Construction Engineering, Swinburne University of Technology, Hawthorn, Australia; Yat Choy Wong, member, Department of Mechanical Engineering and Product Design, Swinburne University of Technology, Hawthorn, Australia, and Suksun Horpibulsuka, member, Department of Civil Engineering and Construction, Swinburne University of Technology, Hawthorn, Australia and School of Civil Engineering and Centre of Excellence in Innovation for Sustainable Infrastructure Development, Suranaree University, Nakhon Ratchasima, Thailand.

The article was published in the scientific journal Journal or Materials in Civil Engineering in November 2016. It talks about the large amounts of plastic and demolition waste produced worldwide. Likewise, about the sustainable and alternative use of these materials; in addition, about the mitigation of waste in landfills and both environmental and economic advantages obtained through this method. In the article

> three types of recycled plastic waste granules were evaluated: linear low density polyethylene filled with calcium carbonate (ldcal), high density polyethylene (hdpe) and low density polyethylene (ldpe) in

mixtures with crushed brick (cb) and recycled asphalt Pavement (rap); evaluating both strength, stiffness and elastic modulus; resulting in polyethylene plastic granules with 5% content proved to be suitable as road construction material, when mixed in supplementary quantities with demolition waste[33, p. 7].

Physical laws of strength and elasticity of materials

Hooke's Law

Hooke's Law arose in the 17th century, formulated by the physicist Robert Hooke when he was observing the elastic behavior of springs and other types of materials. The physicist "observed that for many materials the stress vs. strain curve has a linear region. Within certain limits, the force required to stretch an elastic object, such as a metal spring, is directly proportional to the extension of the spring"[34, para. 9]. The following is a description of the formula found in the Fisicalab page, where Hooke's law is discussed and presents Figure 2 of the present paper as an example. "Hooke's law states that the elongation of a spring is directly proportional to the modulus of the force applied to it, provided that the spring is not permanently deformed" [35, para. 2].

$$F = k. (x-x0)$$

F is equivalent to the modulus of the force applied on the spring, k represents "the elastic constant of the spring, which relates force and elongation. The higher its value, the more work it will cost to stretch the spring. It depends on the spring, so that each one will have its own"[35, para. 3]. Finally, x0 equals the length of the spring without applying the force and x is the length of the spring with the force applied.

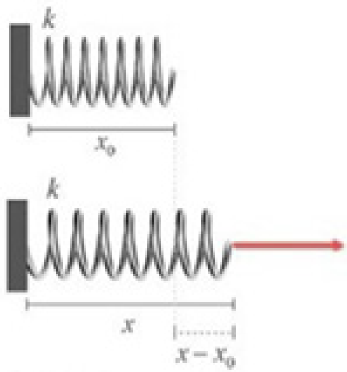

Figure 2. Hooke's Law.
Source: [35].

Young's modulus

Young's modulus or modulus of elasticity is the "number that measures the resistance of a material to being elastically deformed" [34, para. 16]. This measure was observed and studied by the physicist Thomas Young, and determines the relationship existing between deformation symbolized as "dε" and stress as "dσ". The formula for Young's Modulus is described below:

$$E = \frac{d\sigma}{d\varepsilon}$$

Where:
E= Young's modulus – Pascal
σ= stress or force - Pascal
ε = Deformation

A concept of Young's modulus states that "the modulus of elasticity indicates the stiffness of a material: the stiffer a material is, the higher its modulus of elasticity"[36].

Applicability of the bending strength of materials

Bending is the stress applied for the deformation of a constructive element with an elongated shape. Another related concept is the bending moment:

> an object subjected to bending has a point surface called neutral fiber such that the distance along any curve contained in it does not vary with respect to the value before deformation. The stress that causes bending is called bending moment [38].

Bending is described, in terms of stress, as a "transient bending action experienced by an elastic solid under the action of a force that deforms it" [39].

Instron, an expert in materials testing, specifies the performance of this type of testing as follows:

> the specimen is supported by two blades as a single beam and the load is applied at its midpoint. The maximum fiber stress and maximum strain are calculated in load increments. The results are plotted on a load-deflection diagram and the maximum fiber stress is the bending strength. The flexural yield strength is presented for those materials that do not break. Standard test procedures are specified in astm

d-790 (plastics) and astm c-674 (fired white ceramic). astm d-797 (elastomers), astm a-438 (cast iron) and astm d-86 (glass) [40].

Applicability of compressive strength of materials

The compression test determines the resistance of a material or its deformation under crushing stress. Materials are subjected to pressure loads. The specimen is compressed and the deformation is recorded at different loads. The compressive stress and strain are calculated and plotted as a load-deformation diagram, used to determine yield strength, proportional limit, yield point, yield stress and, for some materials, compressive strength. Standard compression tests are provided in astm c-773 (high strength ceramics), astm e-9 (metals), astm e-209 (metals at elevated temperatures) and astm d-695 (plastics) [45].

At present, to build houses in Colombia, it is necessary to comply with the Seismic Resistant Standard (10). This standard arose as a result of the Popayán seismic incident in 1983. With respect to that event, the Congress of the Republic issued Law 11 of 1983, where the steps for the reconstruction of the city were determined. The national government, in one of the articles, authorized mandatory regulations for earthquake-resistant construction, extending throughout the national territory, being "the first national regulation on seismic resistance through Decree 1400 of June 7, 1984, called the Colombian Code of Seismic Resistant Construction" [41, p. 5].

Law 400 of August 19, 1997 was the result of the issuance of a law that would allow updating the regulations by decree in the future, since the powers granted to the President of the Republic lasted only one year. "Under the protection of this law, Decrees 33 of 1998, 34 of 1999,2809 of 2000, and 52 of 2002 were created, which were called Seismic Resistant Construction Regulations nsr"[41, p. 5]. These regulations are in accordance with the provisions of Law 400 of 1997, as well as Decree 926 of March 19, 2010, which establishes the technical and scientific requirements for seismic resistant constructions nsr-10, in its articles 46, 47 and 48.

With the development of Decree 926 of 2010, the mandatory use of seismic-resistant standards was applied throughout the country. Later, with Decree 2525 of 2010, "whereby Decree 926 of 2010 is modified and other provisions are issued, the mandatory application of NSR-10 was deferred until December 15, 2010" [41, pp. 5-6].

Knowledge management and analysis

Initially, in the organization of the material, experimentation was carried out using plastic elements combined with other materials. Likewise, environmental and constructive studies were carried out, observing that in the environmental aspect there is a growing contamination generated by plastic waste that is increasing every day, due to its high use and incorrect reuse. Information was also obtained through interviews related to the programs initiated by the mayor's office of Barranquilla, which has been working to counteract and mitigate the pollution generated by this waste. In the construction field, technological advances applied to eco-sustainable construction at the local, regional, national and international levels were observed and analyzed.

Standards of classification between technology and innovation were established, basing the project at the governmental level, categorized according to Colciencias as "Research, Technological Development and Innovation", also known by its acronym R+D+i[42]. According to the Spanish National Plan for Research and Development, it is stated that R&D&I "is a new concept to the studies related to the advancement of society, being one of the most important parts within information technologies" [50, para. 1].

The importance of deploying this type of research in the region is recognized, being in this case the Faculty of Architecture of the Universidad del Atlántico, support and support for its development and significant contribution to society in general. Due to the above, different types of formulas and materials were used in order to experiment and obtain different results to later analyze them and choose the appropriate one, according to their capabilities and qualities.

The use of ecological construction elements, their composition, their behavior, yielded organized information, establishing variables that made it possible to organize the data and facilitate the field work; likewise, it was possible to follow up and observe the tests, and thus establish the design proposal, its composition and proposed material.

Analysis and selection of materials

With the information on plastics, we proceeded to analyze each component of these materials. Mechanical resistance, resistance to humidity and heat, among others, were studied. It was concluded that the best plastics to work with are type one known as Pet or Pete (pet), type two known as high density polyethylene (hdpe or pead), type four known as low density polyethylene (ldpe or pebd), and type five known as polypropylene (pp), since all of them provide good characteristics to be used in the creation of an ecological brick.

Trial and error

In the production of the ecological material we proceeded to start tests with recycled plastic materials, purchased in the collecting company called Iron Crap Corp Colombia, located in the Circumvalar Avenue in the neighborhood of La Paz, in the city of Barranquilla. The tests made a difference in the evolution of the product, seeking to demonstrate in a synthesized form the evolution of the tests carried out on the material. With the different tests performed, they were subjected to mechanical tests such as bending and compression in a specialized laboratory[43]. Likewise, specific tests were carried out to support the possibility of creating this new product. The material obtained was directed to the construction of an ecological brick model, taking into account all the phases and stages requested. In this search, not only the material was taken into account, but also the proposed designs in different constructive elements. That is why, when designing the brick, several options were sought. The one that attracted the most attention was the conventional hollow red brick model. The model proposed in this document was based on this idea. For the elaboration of the construction element, it was taken into account that it had to comply with the Colombian seismic-resistant norms nsr-10.

Table 1. Properties of pet plastic (-CH_2-CH_2-)n

Feature	
Melting point	Between 244 - 254 °C
Tensile strength	900 kg/cm2
Tensile strength	Between 59 MPa and 72 MPa
Compressive strength	Between 76 and 128 MPa
Water absorption	0.16
Plastic limit	Between 50% and 150%.
Pressure	Between 55 MPs and 75 MPa
Density	Between 1.34 and 1.39 g/cm3
Impact test	3.6 kJ/m2
Thermal conductivity	0.24 W/(m•K)
Coefficient of linear expansion	7×10-5/K
Modulus of elasticity (Young's Modulus)	E= 2800 - 3100 MPa
Refractive index	1.57

Source: based on [47], [44], [25] and [51].

Observation and experimentation were applied. Likewise, with the support of interviews it was possible to clarify doubts to help lower the rates of plastic waste, specifically in the city of Barranquilla. In addition, photographs and videos were used, with the support of the web and the necessary documentation, for the verification of certain hypotheses that would be subjected to laboratory, comprehension and flexural tests.

Material selected for testing

Polyethylene terephthalate (pete or pet)

Plastic pete or pet is used to contain water,

Table 2. Properties of hdpe plastic (C10H8O_4)n

Feature	
Melting point	Between 130 - 137 °C
Tensile strength	Between 22.1-31 kg/cm2
Compressive strength	Between 18.6-24.8 MPa
Bending strength	Between 30.9-43.4 MPa
Fracture toughness	Between 1.52-1.82 MPa•m1/2
Density	Between 0.952-0.965 g/cm3
Crystallinity	Between 70% - 80%.
Poisson's ratio	Between 0.41 - 0.427
Thermal conductivity	Between 0.461-0.502 W/m•K
Coefficient of linear expansion	Between 60e-6 - 110e-6 1/ °C
Modulus of elasticity (Young's modulus)	Between 1.0 - 1.09 GPa
Refractive index	Between 1.53 - 1.55

Source: based on [51].

soft drinks, among other liquids. It is a polymer obtained by mixing several components.

One kilogram of pet is composed of 64% petroleum, 23% natural gas liquid derivatives and 13% air. Paraxylene, extracted from crude oil, allows terephthalic acid to be obtained when oxidized with air. Ethylene, derived from natural gas, is oxidized with air to obtain ethylene glycol. Pet results from the combination of terephthalic acid and ethylene glycol. [46, p. 125].

High Density Polyethylene (HDPE OR PEAD)

Table 3. LDPE (-CH_2-CH_2-)n plastic properties

Features	
Melting point	Between 98 - 115 °C
Tensile strength	Between 13.3- 26.4 MPa
Compressive strength	Between 10.8- 17.4 MPa
Fracture toughness	Between 1.21-3.39 MPa•m1/2
Water resistance (%)	<0,015
Density	Between 0.917-0.932 g/cm3
Crystallinity	Between 40 - 50 %.
Poisson's ratio	Between 0.439 - 0.457
Thermal conductivity	Between 0.322 - 0.348 W/m•K
Coefficient of linear expansion	Between 100e-6 - 200e-6 1/°C
Modulus of elasticity (Young's modulus)	Between 0.172 - 0.283 GPa
Refractive index	1.57

Source: based on [51].

It is a polymer produced as a result of the polymerization of ethylene. It belongs to the olefinic family and is considered a thermoplastic material. It is known as hdpe (High Density Polyethylene) or pead (High Density Polyethylene) [47].

Low-density polyethylene (LDPE OR PEBD)

Low density polyethylene is also known as LDPE (Low Density Polyethylene).

Density Polyethylene) or pebd (low density polyethylene). It is a polymer resulting from the polymerization of olefins. This material "is made up of repeated ethylene units. It is considered an addition polymer and its polymerization process is usually carried out under pressures of 1500 to 2000 kg/cm^2" [48, para. 4].

Low density polyethylene is considered a thermoplastic. Like high-density polyethylene, it is one of the most widely used plastics in the world, since it is used to make plastic bags, greenhouse films, toys, honeycomb bases, among others.

Polypropylene (pp)

This material is a thermoplastic that "is obtained by the polymerization of propylene or propene in the presence of metal alkyl catalysts"[47]. It

Table 4. Properties of Polypropylene (-CH_2-CH(CH_3))n

Features	
Melting point	Between 150 - 175 °C
Tensile strength	Between 27.6 - 41.4 MPa
Compressive strength	Between 25.1 - 55.2 MPa
Fracture toughness	Between 3- 4.5MPa•m1/2
Water resistance (%)	0,03
Density	Between 0.89-0.91 g/cm3
Crystallinity	Between 50 - 60%.
Poisson's ratio	Between 0.405 - 0.427
Thermal conductivity	Between 0.113-0.167 W/m•K
Coefficient of linear expansion	Between 80e-6 - 100e-6 1/°C
Modulus of elasticity (Young's modulus)	Between 0.896 - 1.55 GPa
Refractive index	Between 1.48 - 1.5

Source: based on [51].

can also be found in prostheses, laboratory components, tanks for chemical tanks, hygiene utensils, toys, household utensils, among others.

Classification of plastics according to their toxicity

Plastics have a classification from 1 to 7, as shown above. This categorization is to specify the material according to its use, but not according to its toxicity. This is how plastics are classified as less toxic and more toxic.

The least toxic plastics

Polyethylene Terephthalate (pete or pet) is a material commonly used to make bottles for water drinks, juices, among others. With this material there are discrepancies, as some consider it safe and others do not. The latter claim that "this type of plastic is known to allow bacteria and flavor to accumulate" [49, para. 6].

High Density Polyethylene (hdpe) is a material commonly used for milk cartons, cleaner bottles, shampoo bottles, detergent bottles, among others. "This plastic is one of three plastics that are considered safe, and have low risk of leaching" [49, para. 8]. Low Density Polyethylene (ldpe) is used for the creation of shopping bags and some food packaging. This plastic is "strong, flexible and transparent" [49].

Polypropylene (pp) is considered the "safest" plastic[49, para. 16]. It is used to make yogurt bottles, sherbet bottles, among others.

The most toxic plastics

Polyvinyl chloride (pvc) is one of the most polluting and should be avoided[49]. It is found in pvc plumbing pipes, some detergent bottles, some food wrappings, meat and sausage packages, toys, among others. This type of material has as a negative effect the use of toxic substances such as deha or diethylhydroxylamine, which can be a carcinogenic agent with long term exposure. These plastics used contain phthalates, which are linked to numerous health problems ranging from developmental problems to miscarriages. "Phthalates are a group of plastics that cause some males of many species to become female" [49, para. 11].

Polystyrene (ps) is a material considered as hazardous. This type of plastic arises from "Styrofoam which is famous for being difficult to recycle, and therefore bad for the environment" (Biosalud, 2018). This material, known as white cork, is used for disposable cups or trays.

Number 7 in the classification of plastics is considered to be the worst plastic. According to the International Clinic of Biological Medicine, Biosalud, of Spain, this plastic is deadly, since "it is composed of a mixture of polycarbonate and bisphenol-A (bpa)" [49, para. 18], that is, of all the resins that could not be classified within the previous ones mentioned and that have as a negative effect "infertility, hyperactivity, reproductive problems and other health problems" [49, para. 19].

Procedure

Ten tests were carried out during the months of July to December 2018, as well as in January and February 2019. The above, in order to find the best resistance and texture of the material, choosing some of the most significant test results. These tests show little by little the progress of the field work and evolution of the materials/products, to determine their properties of mechanical strength, tensile strength, flexural strength, humidity and amount of temperature that the bricks can withstand before melting in case of fire.

Analysis and interpretation of results

Based on the review of research and tests performed during all the tests during the second half of 2018, from July to December, and also the extra time from January to February 2019, it was observed, during the first plastic tests, only pet plastic. The time at which the material began to soften at a temperature point of 100 °C and finished melting at a temperature range of 250 °C to 300 °C was reviewed.

In the tests carried out with pet plastic, it was noted that constant movement of the mixture was necessary to avoid its rapid crystallization. In the process of the melted material, it is noteworthy that, after taking a liquid consistency, when it cools down, cracks appear. The tests, although they showed a certain hardness of the material, evidenced that it did not resist the impact force sufficiently and broke immediately.

This led to focus the research on the other plastics, i.e. high density polyethylene plastic (hdpe or pead), low density polyethylene plastic (ldpe or pebd) and polypropylene plastic (pp), which were tested, resulting in a more impact resistant material, with good characteristics and results of compressive strength and flexural strength.

Conclusion

It is concluded that, in the prototype for the brick, the various studies carried out in this document should be taken into account. It was determined that the measurements of the brick are 20 cm high × 12 cm wide × 40 cm long and its design was made in the Sketchup program. Regarding the applicability of the material, it is considered that the product made of plastic and other complementary materials has a variety in its applicability, since it is a material that can be molded according to its need. Studies show that this material has good resistance to compression and bending tests. In addition, it can be stuccoed without any problem and subsequently painted. The product can be molded for use in the construction of load-bearing and garden walls, partition walls, tiles, paving stones, among others.

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