Elaboration of an eco-brick for construction with improved physical and mechanical properties

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Abstract. This study aims to develop a sustainable masonry product (light brick) for construction with improved physical and mechanical properties. In the eco-brick manufacture, raw materials such as cow dung and coffee stem were used, crushed, and joined with a binder material such as general-purpose cement to increase the mechanical resistance of the eco-brick. During the eco-brick manufacturing process, the cow dung is dried, exposed to the sun for two days, and mixed with hydrated lime, the material by eliminating toxins and bad odors. The results showed that the eco-bricks presented a lower value in their compression resistance with additions of 2:1, 2:2, 2:3 with average resistance of 3.34, 3.70, and 4.5 MPa, respectively compared to the common brick (8.28 MPa), these values indicate a reduction in the compression resistance around two times compared with common brick. On the other hand, the eco-bricks did not present fractures after the compression test. In addition, the eco-brick densities correspond to medium type according to the literature. Finally, this research aid in promoting the rational use of available resources, applying Colombian standard procedures for elaborating masonry products, thus establishing those eco-materials can be used to construct sustainable homes due to their non-polluting in the manufacturing process.

1. Introduction
Traditionally in construction, bricks are one of the most used materials in masonry products. Bricks are characterized by great durability and compression resistance properties, but their main weakness lies in the low resistance to traction and changes in humidity [1-3]. Some advances have determined that natural fibers could aid improve the structural (mechanical) properties of the bricks, thus giving a new area for future research [4,5]. Furthermore, different studies have demonstrated the great physicochemical properties that provide the natural resources [6]; thanks to this, materials and products derived from vegetable fibers have been developed, providing good and practical use to be incorporated in the masonry industry [7,8].

Solid clay bricks are used to construct civil projects, mainly in buildings and homes. This behavior is due to the low costs of the raw materials, availability, physic, and mechanical properties such as thermal insulation and compression resistance [1,9]. During their useful life, homes and different constructions are subject to vertical and horizontal loads, which can generate fractures in masonry products and walls [10,11]. Notice that if its quality is not adequate, it can endanger the home inhabitants. Considering that fracturing influences an increase in its vulnerability, mainly due to seismic action [12]. Nowadays, the constructions with masonry with natural fibers such as plantain and cow dung fiber have not been implemented due to misinformation regarding renewable materials, which can have a low environmental impact. Notice that the fibers can be influenced in all types of masonry
projects; simultaneously, it is a system completely adapted to the climate in humid countries (dry and wet) with many natural resources available [13,14].

Considering the above, the main objective of this work is to develop an eco-brick based on different substitutions of cement, cow dung, and coffee stem with different geometries. Furthermore, the mechanical and physical properties of the eco-brick were evaluated considering the guidelines of the Colombian Technical standard procedures using a universal test machine. The results indicate that the eco-brick had a great capacity to support axial loads with the substitution materials. Also, the resistance-density relationship is directly proportional to increasing the mass without altering the initially established volume and the degree of compaction in the pressing brick process, reducing the existing pore pressure and thus its resistance increases.

2. Methodology and materials

This research has a quantitative approach and experimental type. The percentage of incorporation of cow dung and the coffee stem is used to elaborate an eco-brick with cement is used in this study. Likewise, the hypothetical and deductive method was used to validate the results obtained, considering the problem a hypothesis originates, which is verified through the empirical and scientific methods. However, it is proposed to answer six questions that will aid to understand better the research process, such as (1) Is brick based on cow dung, coffee stem, and cement lighter than conventional? (2) His mechanical resistance is greater? (3) Does it resist sudden and moderate changes in temperature? (4) Is the eco-brick cheaper than the conventional one? (5) How will it be accepted in society? and (6) the eco-brick reduces the environmental impact produced by this industry.

2.1. Characteristic of the materials used in the eco-brick

The cow dung was obtained from a farm located in Ocaña, Colombia. This raw material was selected manually and put to dry exposed to the sun for two days to eliminate odors and excess moisture. After this process, the material was sifted into a No 4 sieve to obtain adequate granulometry and remove the largest particles and other materials. Regarding the coffee stem, this corresponds to the surplus from the coffee bean processing. Then was processed through drying and milling to obtain a sufficiently homogeneous material with adequate granulometry. Figure 1 shows the homogenization of the material of cow dung Figure 1(a) and coffee stem Figure 1(b).

![Figure 1](image1.png)

(a) processed cow dung material; (b) processed material of coffee stem.

3. Results and discussions

Initially, the homogeneous mixture of raw materials (cow dung and coffee stem with cement) was considered. Then, a manual press machine was used to obtain brick samples with different substitutions, as indicated below.
3.1. Eco-brick samples with different substitutions

In the first experimental design for the eco-brick, a substitution of 1:2:4 was considered (1 = cement, 2 = cow dung, and 4 = coffee stem). Initially, the materials were prepared (washed, crumbled, drying, and sifted) for the correct use in the brick manufacturing process. After, the homogeneous mixture was pressed in the manual pressing machine (simbarran) used to manufacture the eco-bricks, as shown in Figure 2. Then, a substitution of 1:2:4 was applied for the eco-brick corresponds to 9.44 kg of cement, 5.87 kg of cow dung, 6.4 kg of the coffee stem in its entire state, and 4 liters of water, obtaining a homogeneous mixture and thus was compressed in the manual press machine (simbarran). Notice that if the substitution does not show consistency and homogeneity is considered a failed design. Due to this behavior, a 1:2:3 substitution was established, based on the mistakes that did not contemplate in the 1:2:4 substitution, which were the size of the coffee stem particles. In this way, a substitution of 1:2:3 was considered in the mixture with 9.44 kg of cement, 5.87 kg of cow dung, and 4.8 kg of the coffee stem where was obtained a conformable eco-brick.

On the other hand, a mixture composition with a higher quantity of cement, higher humidity, and without compacting was used, with a substitution of 2:2:3, using 1.33 kg of cement, 0.550 kg of cow dung, and 0.450 kg of the coffee stem, respectively. In its natural state, the weight of the material varied as the volume of the mold changed. Then was allowed to dry for 15 days to obtain the first non-resistant brick, which showed consistency but not resistance in its already solid state. Likewise, a 2:3:4 substitution was considered where a type of treatment was used on the coffee stem, using a mill that crushed the material, thus obtaining finer and more compressible particles (granulometry) coffee stem in its state of obtaining is not suitable to compress.

This design was handled with a substitution of 2:3:4, using 1.33 kg of cement, 0.825 kg of cow dung, and 0.60 kg of the coffee stem, with a water/cement ratio of 0.45, notice that the value of 0.45 is adequate for a mix design with utility in the casting of structural elements in concrete. This brick sample was the first to present consistency and little resistance, thus appearing in its initial state as a biscuit since its manufacturing process did not carry excellent compaction.

Eco-brick samples with substitution of 2:2:3 was established without compacting to reduce the brick volume, obtaining uniform measurements of 20 × 12 × 6 cm, which corresponded to a mold of dimensions 20×12×10 cm. For this substitution, general use portland cement type 1 was used. Thus, the 2:2:3 substitution, a machine crushing the cow dung and crushing the coffee stem until obtaining very fine particles like powder, was 1.33 kg of cement, 0.55 kg of cow dung, and 0.45 kg of cement were used. Notice that a water ratio of 0.25 to cement in the mixture method, thus obtaining a homogeneous material ready to be compressed in the manual press machine. In the compressed process, were applied around 100 strokes to reduce the porosities on the eco-brick, thus obtaining eco-bricks with consistency and not deforming, as was evidenced by the other substitutions.

Finally, with the previous manufacturing procedure for the eco-bricks, was considering the last substitution of 3:2:4 where the amount of cement and coffee stem was increased thus were contemplated in the mixture values of 2.655 kg of cement, 0.55 kg of cow dung, and 0.60 kg of the coffee stem with a water ratio of 0.25 to cement. Figure 3 shown the final eco-brick after desmoulding.
3.2. Mechanical behavior of the eco-brick

The resistance analysis of the eco-brick was carried out in comparison with common fired clay brick manufactured in the region. In this way, a compressive resistance test was developed in both types of bricks with the NTC 4017 standard [15] Colombia procedure guidelines. In addition, the NTC 4205 standard [16] Colombia procedure was also considered due to the limited parameters of this type of brick as a masonry product for construction.

The dimensions of conventional clay brick are $23 \times 12 \times 6$ cm with strength values between 10 MPa to 15 MPa (1450 PSI to 2275 PSI) for non-structural use in masonry. However, the eco-bricks based on cow dung, coffee stem, and cement is a brick of lower density than the common one since its contact area is smaller due to its length, and due to the manufacturing process that it presents, it still does not comply with the requirements demanded by the NTC standard [15,16]; for example, comparing the substitution of 2:2:3, which reached a resistance greater than 0.125 required in the NTC 4205 standard [16], but no more than 0.333 achieved by the common clay brick. However, the second substitution of 3:2:4 improved the results compared to the substitution of 1:2:3, reaching resistance of no more than half required by the NTC 4205 standard [16], and more than half the resistance of that obtained in the common brick.

3.3. Results of the compressive resistance test on the eco-brick

The objective of this test was to determine the eco-brick mechanical properties against negative axial forces. The results obtained from the compressive resistance are summarized in Table 1, showing the percentage of substitution, weight, dimensions, load, and strength found from the mechanical and physical tests for each experimental condition. From Table 1 was observed that both bricks (common clay and eco-bricks) did not have the average dimensions considering the NTC 4205 standard [16]; this may be due to the manufacturing procedure. The compression resistance values are mainly observed that the values can change as a function of the dimensions of the brick (morphology). On average, the lowest resistance was obtained for the first substitution 2:2:3, with a maximum value of 2.13 MPa. Notice that the substitution corresponding to 3:2:4 of substitution without compacting achieved a maximum compression resistance of 16.77 MPa, due to the manufacturing procedure and granulometry of the mixture [17,18].

| Table 1. Compressive resistance test values. |
|---------------------------------------------|
| Substitution | Weight (Kg) | Dimensions | Load (kN) | Strength |
|              |             | Length (cm) | Width (cm) | Thickness (cm) | (Pa) | (MPa) |
| First        |             | 12.0       | 6.0        | 51.0 | 2129.17 | 2.13 |
| 1.1          | 1274        | 20.0       | 12.0       | 2.0  | 1476.03 | 1.48 |
| 1.2          | 1225        | 19.5       | 11.5       | 33.1 | 1470.83 | 1.47 |
| 1.3          | 1508        | 20.0       | 12.0       | 35.3 | 1470.83 | 1.47 |
| Second       |             | 12.0       | 6.0        | 80.2 | 3341.67 | 3.34 |
| 2.1          | 1689        | 20.0       | 12.0       | 88.7 | 3695.83 | 3.70 |
| 2.2          | 1551        | 20.0       | 12.0       | 97.0 | 3880.00 | 3.88 |
| 2.3          | 1964        | 12.5       | 7.0        | 190.5 | 8282.61 | 8.28 |
| Third        |             | 13.0       | 6.0        | 217.6 | 9066.67 | 9.07 |
| 3.1          | 1984        | 20.0       | 12.0       | 402.4 | 16766.70 | 16.7 |
| 3.2          | 1941        | 12.0       | 6.0        | 301.6 | 12566.70 | 12.5 |
| 3.3          | 1767        | 12.0       | 6.0        | 211.3 | 8804.17 | 8.80 |
| 3.4          | 1929        | 12.0       | 6.0        | 190.5 | 8282.61 | 8.28 |
| Common brick |             |            |           | 195.6 | 7409.09 | 7.41 |

The eco-bricks in their final state after the compression test maintained a uniform deformation; due to this, it could be considered a plastic material. After all, it did not present any fracture after the point.
of failure, otherwise with clay bricks, because it presented fractures in its faces. In the compression resistance test of the eco-brick, it was obtained that the bricks with higher density presented higher mechanical resistance results. In addition, it was observed that there is a proportional relationship between density, compaction, and resistance in the manufacture of bricks.  

4. Conclusions 
This eco-brick proves to have a great capacity to support axial loads, thus satisfying the demand for non-polluting masonry products, aiding the sustainability of the environment, thus avoiding the exploitation of non-renewable materials that alter ecosystems.  
The resistance-density relationship is directly proportional due to increasing the mass without altering the initially established volume and the degree of compaction made in the pressing brick process, thus reducing the existing pore pressure and its resistance increases. Additionally, it was observed that the particle size of the coffee stem affects adherence with the other mixture design components when is used; a large particle size with which this material is collected is preserved, which conserves a large amount of air that remains trapped in the brick structure.  
Different binder materials such as lime, type I Portland cement, and type III Portland cement, infer the drying time and the resistance of the eco-brick. Note that lime increases the plasticity of the mixture by altering its chemical components, avoiding the water retention property due to the exothermic reaction that it generates. The Portland cement type I generates a good resistance in the eco-brick due to the chemical components and microstructural property that hardens the brick, preserving the resistance and the required stability. Finally, the type III Portland cement improves conditions at an early age in 7 to 15 days, unlike type I, which takes approximately 28 days to reach high strength.  
It was established that the use of unconventional materials in the manufacture of brick promotes a hard way to know its behavior in different conditions due to the few studies that have been done since the ecological environment involves the inclusion of plastic and non-organic materials. Both eco-bricks in their manufacturing process present similarities in the physical and mechanical properties. However, they cannot be compared since the cost of manufacturing the eco-brick is higher than the common one. Still, it is lower than the cost of manufacturing eco-bricks with the addition or substitution of inorganic materials.  
It was also possible to demonstrate that the elaboration of bricks with cow dung, coffee stem, and cement can be used to design a masonry product with good mechanical properties. The eco-bricks presented good compression resistance values to be used in structural masonry with excellent physical and mechanical properties such as low density and a good insulator.  

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