recycling

Article

Mechanical and Market Study for Sand/Recycled-Plastic Cobbles in a Medium-Size Colombian City

Luz Adriana Sanchez-Echeverri [1,*], Nelson Javier Tovar-Perilla [2], Juana Gisella Suarez-Puentes [2], Jorge Enrique Bravo-Cervera [2] and Daniel Felipe Rojas-Parra [2]

[1] Facultad de Ciencias Naturales y Matemáticas, Universidad de Ibagué, Carrera 22 Calle 67, Ibagué 730002, Colombia

[2] Facultad de Ingeniería, Universidad de Ibagué, Carrera 22 Calle 67, Ibagué 730002, Colombia; nelson.tovar@unibague.edu.co (N.J.T.-P.); 2320161060@estudiantesunibague.edu.co (J.G.S.-P.); 2520161019@estudiantesunibague.edu.co (J.E.B.-C.); 2520162037@estudiantesunibague.edu.co (D.F.R.-P.)

* Correspondence: luz.sanchez@unibague.edu.co; Tel.: +57-8276-0010

Abstract: The need to satisfy the increasing demand for building materials and the challenge of reusing plastic to help improve the critical environmental crisis has led to the recycling of plastic waste, which is further exploited and transformed into new and creative materials for the construction industry. This study looked into the use of low-density recycled polyethylene (LDPE) to produce non-conventional plastic sand cobbles. LDPE waste was melted in order to obtain enough fluid consistency which was then mixed with sand in a 25/75 plastic-sand ratio respectively, such a mixture helped producing cobbles of 10 cm × 20 cm × 4 cm. Water absorption, weight, and density measurements were performed on both commercial and non-conventional plastic sand cobbles. Moreover, compression, bending, and wear resistance were also conducted as part of their mechanical characterization. Plastic sand cobbles showed lower water absorption and density values than commercial cobbles. The mechanical properties evaluated showed that plastic sand cobbles have a higher modulus of rupture and wear resistance than commercial cobbles. In addition, plastic sand cobbles meet the Colombian Technical Standard in lightweight traffic for pedestrians and vehicle, officially known as Norma Técnica Colombiana (NTC), with 25.5 MPa, 16.3 MPa, and 12 mm compression resistance, modulus of rupture and footprint length in wear resistance respectively. Finally, a market study was conducted to establish a factory to produce this type of cobbles in Ibague, Colombia. Not only the study showed positive financial indicators, which means that it is feasible running a factory to manufacture plastic sand cobbles in the city of Ibague, but it also concluded that nonconventional plastic sand cobbles could be explored to provide a comprehensive alternative to LDPE waste.

Keywords: materials; recycling; plastics; cobbles; lightweight traffic; pedestrian traffic

check for updates

Citation: Sanchez-Echeverri, L.A.; Tovar-Perilla, N.J.; Suarez-Puentes, J.G.; Bravo-Cervera, J.E.; Rojas-Parra, D.F. Mechanical and Market Study for Sand/Recycled-Plastic Cobbles in a Medium-Size Colombian City. *Recycling* **2021**, *6*, 17. https://doi.org/10.3390/recycling6010017

Received: 25 January 2021
Accepted: 26 February 2021
Published: 4 March 2021

1. Introduction

Plastic consumption and its latter disposal have become a problem due to the high volume of waste and the huge environmental impact they have, not only for the human population, but also for ecological systems [1–3]. Plastic is a versatile material with wide applications. However, it is a material that people do not consume correctly as there are no perceived dimensions on the environmental damage that its use entails [4,5].

Per capita plastic consumption continues to rise and remains high in high-income countries, despite obvious contributions to the global issue of plastic pollution [6]. In 2015, the World Bank concluded that if waste generation maintains the same dynamic without adequate actions to improve reuse, unsustainable use, and production, it will have become a health emergency issue in most countries. This is in addition to high greenhouse gas emissions by 2030.

Our planet is not capable of digesting the plastic waste generated daily and this will continue to happen. The best evidence is in the 4977 Mt of plastic waste accumulated in landfills or natural environments up until 2015 [7]. In Colombia, each person consumes an average of 2 kg of plastic per month, 24 kg per year, this means 1250 Mt per year in the country [8]. In 2018, about 31,500 t/day of plastic waste was disposed of in landfills, treatment plants, and waste cells—which means that of the 11.4 Mt of plastic waste in the year, only 17% was recycled [9]. The above situation shows what awaits humanity. Despite global efforts to solve these problems throughout recycling, plastic production has grown at a much higher rate. Plastic waste control cannot be achieved under the current circumstances. In Ibagué, Colombia, there are no waste management programs that could impact the population around recycling. For example, in 2018 only 4% of the city's waste was reused, because of the absence of recycling-companies in the region [10]. This poor level of recycling is constantly creating a crisis in the country's landfills due to the lack of waste disposal space. If viewed in a five-year perspective, the problem only tends to get worse, as it is estimated that 321 landfills in the country will reach their lifespan [11].

Different plastic recycling strategies have been proposed around the world: mechanical (classification, crushing, and cleaning), chemistry (pyrolysis, hydrolysis and glycolysis) and energy (plastic waste is used as fuel to produce electricity, steam, or heat) [12]. However, low-income countries have inadequate solid waste management with low waste collection rates; recycling infrastructure for these materials often does not exist in these countries. As a result, waste plastics have little or no value, resulting in uncontrolled disposal or leakage in the wild [6,13,14].

Another important sector that generates high environmental impact is the building and construction industry. For this reason, this industry has been interested in the development of more sustainable materials in recent years. To address this problem there has been development of cement-based materials with natural fibers using fewer polluting treatments or the replacement of cement with waste from different sources such LCD or e-waste [15–19]. However, cement, which is a high contaminant material, remains the main compound of these materials. In order to produce new materials with low cement content, there are different studies that have developed building materials from plastic waste [20–22], and in this way avoid tons of single-use plastic waste ending up in landfills.

Most of the plastic used in the manufacturing of these new building materials is polyethylene terephthalate-PET, which is plastic with the highest recycling percentage so far [23,24]. PET bottles have been used to make ecofriendly bricks; bottles are filled with sand or food wrappers [25,26]. Crushed PET has been used as an aggregate in the manufacturing of asphalt, concrete, and soils that show advantages such as weight reduction, corrosion resistance, and proper mechanical performance [27,28]. Although efforts to use plastic waste in the manufacturing of new building materials have shown good results, they still leave out alternatives for the use of a different type of plastic other than PET.

In order to create new materials from single-use plastic, in Africa the manufacture of construction blocks based on sand and plastics materials from Low Density Polyethylene-LDPE have been developed. LDPE is a type of single-use plastic that represents an environmental issue [29,30]. The manufacturing of these blocks has led examples of a community-driven waste management initiative that has had an impact on local communities and local waste management [31], not only as a job source but also for the implementation of these blocks in the poor condition's roads.

Kumi-Larbi Jnr, et al. (2018) have reported the manufacturing process to a laboratory scale of blocks using LDPE plastics only from water sachets [32]. However, there is no reported manufacturing process from other sources. This paper evaluates the mechanical performance of cobbles for pedestrian use based on plastic sand mix. Additionally, the market research and financial study are for the start-up of a manufacturing plant in Ibagué, Colombia of these non-conventional blocks with the aim to propose an alternative for an integrated waste management system.

2. Materials and Methods

2.1. Manufacturing of Plastic Sand Cobbles

LDPE is a thermoplastic that can be repeatedly molded when heated with a density in the range of 0.91–0.94 g/cm^3, with a melt temperature around 140 °C and water absorption <0.01%. LDPE from different plastics waste was supplied by a local recycled plastic bags manufacturer, LDPE was obtained crushed and pelletized in a 3 mm diameter to facilitate its melt; sand was supplied by local building materials enterprise (HOMECENTER SODIMAC corona). Figure 1 shows the raw materials used to manufacture plastic sand cobbles (see Figure 1).

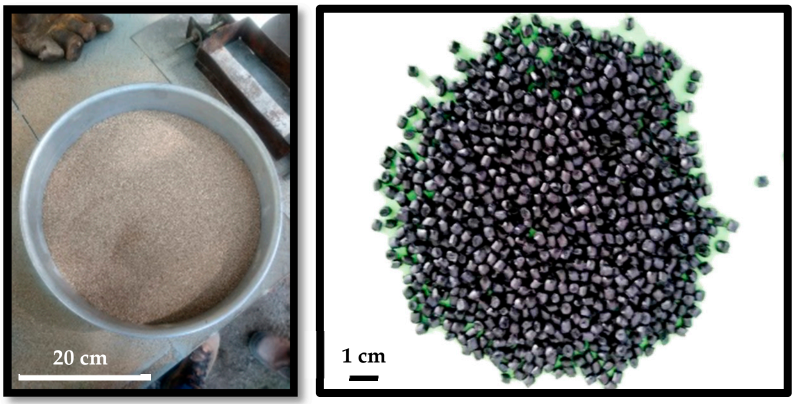

Figure 1. Sand and plastic pellets used in the manufacturing of plastic sand cobbles.

Commercially available silica sand was used as an inert filler with a particle density of 2.65 g/cm^3 with 1.1% of fine aggregate and a sieve analysis (INV E 123-13) shows in Figure 2.

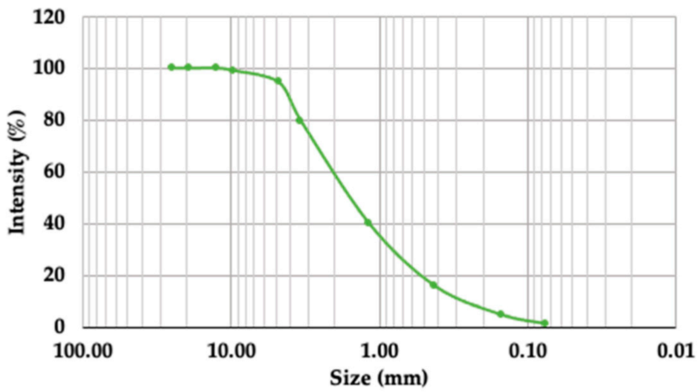

Figure 2. Sieve analysis for commercially sand used in the sand/plastic cobbles.

The sand was previously baked dry for 24 h and sifted with particle sizes of <1.00 mm diameter as is suggest in previous results [32].

For LDPE plastic sand cobbles, a mixture with a ratio of 25/75 respectively was used due to previously reported studies; for this work 1600 g of sand and 400 g of plastic pellets were employed for the cobbles manufacturing. The process flow diagram, as well as the plastic sand block obtained, are shown in Figure 3. The plastic pellets are melted in an oven at 180 °C ± 5 °C; once the plastic had the proper consistency the sand was added and mixed continuously until obtained a homogeneous mix. The mixture was placed in a 10 cm × 20 cm × 4 cm casting mold. Two hours after the sample was demoulding, and it was kept at room temperature before the analyses; a total of 18 cobbles were manufactured to carried out the different tests; 5 for each mechanical testing (MOR and Compressive strength), 5 for water absorption and only 3 for wear resistance due the test was developed in an external laboratory, the same quantity of commercial cobbles was tested. The physical characteristics (dimensions, density and weight) of both cobbles sand/plastic and commercial were determinate in the 18 samples because they are nondestructive testing.

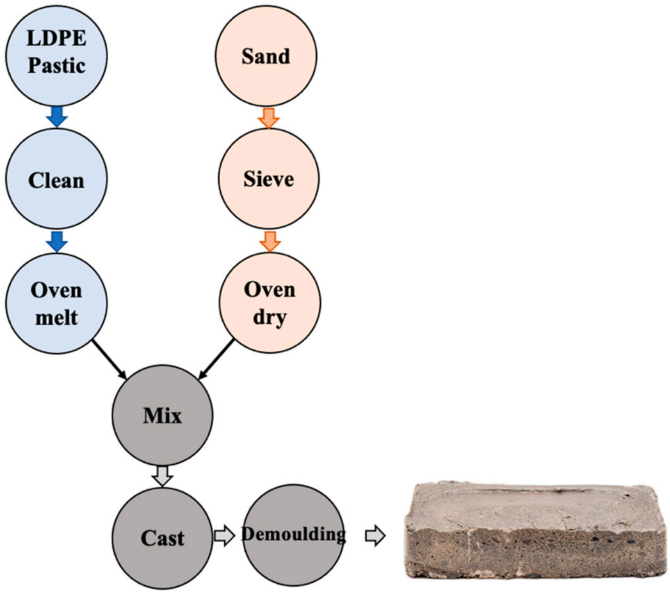

Figure 3. Flow diagram for plastic sand cobbles manufacturing.

2.2. Plastic Sand Cobbles Characterization

LDPE plastic sand blocks were characterized and compared with commercial blocks of pedestrian use. The water absorption of samples was determined after 24 h of immersion in distilled water at room temperature, as described in ASTM D570. Density and dimensions were calculated by direct measurements as is indicated in the Colombian Technical Standard, known officially as Norma Técnica Colombiana (NTC 2017-Pavement concrete cobblestones) [33]. Water absorption for plastic sand and commercial cobbles was calculated following equation

$$\text{Water absorption } (\%) = [\frac{Ww - Wd}{Ww}] * 100\%, \quad (1)$$

where:

Ww = Wet weight of specimen [g]
Wd = Dry weight of specimen [g]

Tests were performed for the mechanical characterization of the modulus of rupture (MOR) and compression resistance of both the plastic sand and commercial cobbles. A three-point load bending test with a span of 200 mm and a speed of 10 mm/min was performed in accordance with Colombian Technical Standard [33] on a JJ Lloyd traction test machine. Dry specimens were tested in a room in a controlled environment at 23 °C ± 2 °C and a relative humidity of 50 ± to 5%. Equation (2) determines the modulus of rupture and Figure 4 shows a detail of variables involved:

$$\text{MOR} = \frac{3L_{max}(l_i - 20)}{[(w_r + w_i)\, e^2]}, \quad (2)$$

where:

L_{max} = Maximum load [N]
l_i = Length of inscribed rectangle [mm]
w_r = Real width [mm]
w_i = Inscribed rectangle width [mm]

e = Thickness [mm]

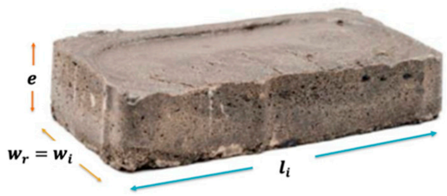

Figure 4. Representation of variables involved in Modulus of Rupture.

Finally, the wear resistance of plastic sand and commercial cobbles was determined on the basis of Colombian Technical Standard, (NTC) 5147 2002 (This standard is the determined test method for measuring resistance to abrasion of materials for floors and pavements; this test is used to determine the abrasion resistance of floor and pavement materials by sand and width of disc). The cobbles were subjected to wear by means of abrasion exerted, under controlled conditions, by a flow of sand that passes tangentially between that surface and the side face of a metal disc, which exerts pressure against it. This generates a footprint, in the shape of the curved surface of the metal disc (Figure 5).

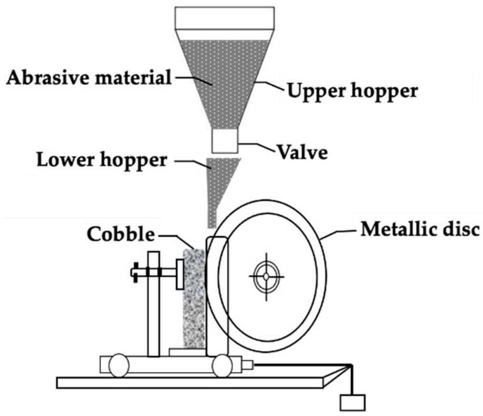

Figure 5. Sketch of wear resistance test for commercial and sand/plastic cobbles.

After test, the footprint generated was measured as follows Equation (3)

$$f_l = AB + (200 - V_c), \tag{3}$$

where:

f_l = Length of footprint [mm]
AB = Length of footprint in the center point [mm]
V_c = Calibration value [mm]

The resulting length is inversely proportional to the abrasive wear resistance, which the sample possesses. The test was carried out in 3 samples in order to obtain an average abrasion resistance value.

2.3. Market Research—Case of Study: Ibagué, Colombia

This study encompasses all the necessary and relevant information to determine the feasibility of investment in this type of project. The feasibility study covers four main areas: Market Study, Technical Study, Organizational Study, Financial Study [34].

Market Study: The market study will indicate the acceptability of the cobbles. The target population was companies and entities based in the city of Ibagué with economic activity characterized by the purchase or marketing of cobblestones. The population was segmented in accordance with the International Uniform Industrial Classification (IUIC) of Higher Education Institutions: agro-tourism farms and companies dedicated to the construction of pedestrian roads and hardware stores [35]. Equation (4) with a confidence level of 10% was used to determine the sample size.

$$n = \frac{Z^2{}_{\propto} \cdot N \cdot p \cdot q}{i^2(N-1) + Z^2{}_{\propto} \cdot p \cdot q}, \tag{4}$$

where:

n: Sample size
Z: Value corresponding to Gauss distribution for significance level α (for 10% significance takes the value of 1.64)
N: Population size (2246 companies)
p: Expected prevalence of the parameter to be evaluated, if p = 0.5 is unknown (q: $1-p$)
i: Error expected to be made (10% $\times$ 0.1)

Interviews were conducted with the people in charge of the sales or purchase of building materials in order to know the level of acceptance of plastic sand cobblestones and the demand of the product in the market.

Financial Study: Compiles all financial information for the implementation of such projects and converts it to monetary terms to look at the approval or rejection of the proposal.

3. Results and Discussion

3.1. Physical Characteristics of Cobbles

The physical characteristics of plastic sand and commercial cobbles after manufacturing are shown in Table 1.

Table 1. Physical characteristics of plastic sand and commercial cobbles.

Physics Characteristics	Plastic/Sand Cobble	Commercial Cobble
Length [cm]	19.20 [a] 0.87 [b] 0.21 [c]	20.01 [a] 0.11 [b] 0.03 [c]
Width [cm]	9.50 [a] 0.33 [b] 0.08 [c]	10.00 [a] 0.09 [b] 0.02 [c]
Thickness [cm]	4.00 [a] 0.27 [b] 0.06 [c]	5.90 [a] 0.21 [b] 0.05 [c]
Weight [g]	1232.60 [a] 118.02 [b] 27.82 [c]	2438.94 [a] 121.87 [b] 28.72 [c]
Density [g/cm^3]	1.59 [a] 0.10 [b] 0.02 [c]	2.08 [a] 0.06 [b] 0.01 [c]
Water absorption [%]	2.56 [a] 0.78 [b] 0.35 [c]	6.30 [a] 1.50 [b] 0.67 [c]

[a] Mean, [b] Standard deviation and [c] Typical Error.

According to the Colombian Technical Standard for pedestrian and light vehicle traffic [33], the dimensions of the cobblestones (concrete cobblestones for pavement) must be 100 mm < length $\leq$ 250 mm, width $\geq$ 100 mm and 40 mm < thickness $\leq$ 60 mm. According to dimensions, the results of cobbles produced with plastic waste and sand samples obtained the necessary dimensions to be marketed as pedestrian or light traffic vehicle cobbles. This is a wide potential market. Based on mass and density results, the addition of plastic in the cobbles reduces the weight and density of the sample by 49.46% and 23.56% respectively. This implies the production of lighter materials; it has been shown to be an advantage in the search for new building materials [36]. Lightweight materials reduce the cost of transportation and marketing. In addition, conventional brick masonry was ranked highest in terms of CO_2 emissions, while sand lime masonry which is light in nature, was ranked as the lowest [37]. Finally, water absorption, which is the capacity that water has to penetrate into samples, is closely related to porous distribution and porosity of materials. This is an important indicator of long-term mechanical properties. According to the results of Table 1, the plastic sand cobbles reduce water absorption by approximately 60%. This reduction is due to the hydrophilic nature of plastic. Plastic sand cobbles showed an improvement in resistance to water absorption, and this behavior is based on previous results of bricks containing crushed glass and polypropylene granules [38,39]. According to water absorption results and based on the Colombian Technical Standard (NTC) 3829

(Clay Cobblestone for Pedestrian Transit and Light Vehicle) plastic sand cobbles could be classified as Type I. This means that cobbles can be exposed to high abrasion environments.

3.2. Mechanical Characteristics of Cobbles

The modulus of rupture (MOR) and the compression resistance of plastic sand and commercial cobbles are shown in Table 2; for MOR values, the thickness of the cobbles was measured at four different points and the mean value was used. MOR is the most important mechanical feature for this type of materials used for pedestrians and light traffic because they work predominantly in bending. The plastic sand cobbles rupture module is 1.5 times larger than commercial. However, the dispersion obtained for plastic sand cobbles is greater than its commercial counterpart due to its artisanal manufacturing process, which made differences in the final material. Different studies have shown an increase in the modulus of rupture of building materials with addition of plastic, which agrees with the results found here [39,40]. On the other hand, compression resistance is higher for commercial sand cobbles than for the plastics ones.

Table 2. Compression Modulus of rupture of commercial and plastic sand cobbles.

Type of Cobble	Compression Resistance (MPa)	Modulus of Rupture (MPa)
Commercial cobbles	30.60 [a] 3.40 [b] 1.52 [c]	6.03 [a] 0.40 [b] 0.17 [c]
Plastic sand cobbles	25.49 [a] 1.70 [b] 0.76 [c]	16.28 [a] 2.51 [b] 1.12 [c]

[a] Mean, [b] Standard deviation and [c] Typical Error.

Wear resistance is one of the parameters for measuring the durability of materials exposed to different environments. The length of the footprint after the wear test was 21.10 mm ± 0.66 mm and 12.43 ± 0.80 mm for commercial cobbles and plastic sand cobbles, respectively. Arango-Londoño (2006) determined an average footprint length of 21.7 mm for concrete cobbles with a maximum value of 23 mm [41]. These values match the commercial cobbles studied and are in accordance with the recommended values for various standards [42]. Wear resistance has no association with the other mechanical characteristics analyzed because it behaves as a separate variable. Therefore, it must be specified as a product quality control test independently, without being indirectly controlled from other variables. For regulatory purposes, it is recommended to specify a maximum tread length in the abrasion resistance test of 23 mm [41].

In accordance with the requirements of the Colombian Government for Pedestrian Areas and Light Traffic Areas, the standard establishes minimum values of 10 MPa of MOR tests under dry conditions for vehicle traffic, 6% and 8% water absorption for pedestrian and vehicle traffic respectively, 55 MPa and 69 MPa of compression resistance for pedestrian and vehicle traffic respectively, and 0.11 of the abrasion rates for both uses of pedestrian and vehicle traffic. According to this standard, the results obtained in the physical and mechanical characterization of the plastic and sand mixture allow to obtain suitable materials for these applications. Moreover, they allow the reduction of plastic waste and they could contribute to reduce the water crisis due the manufacture process do not consume this resource.

3.3. Market and Financial Study on Ibagué

Table 3 shows the target population and sample size calculated according to Equation (1); the results were obtained based on information of companies registered to the Ibague Chamber of Commerce as of 31 May 2018.

In order to know the demand for these types of products, purchase frequency was investigated, showing that the daily and weekly frequencies of purchase were more recurring (Figure 6). In addition, the most representative entities in this frequency of purchase are retail hardware stores which represent 69.2% of the target market, and wholesale stores representing 15.4% of the target market. With these results, it was identified that it is necessary to adopt a production process that can meet a market with daily and weekly demand.

Table 3. Target population and sample size calculated for the market study of the start-up of a nonconventional plastic sand cobbles plant in the city of Ibague—Colombia.

Activity	CIIU Code	Total	Sample
Farms–Rural accommodation	I5514	77	2
Non-permanent tourist housing, excluding hourly	I5519	46	1
accommodation	G4752	1554	46
Retail trade in hardware items	G4663	346	10
Wholesale trade in building materials and hardware	F4390	178	5
items	P8543	6	1
Other specialized activities for the construction	P8523	39	1
	Total	2246	66

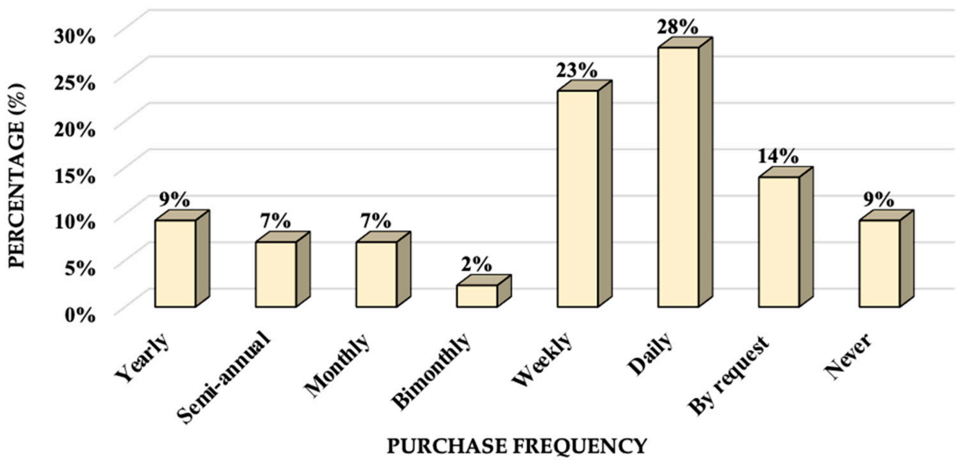

Figure 6. Frequency of purchase of cobbles for pedestrian use or light vehicle traffic.

Once demand behavior is known, it is necessary to determine what type of companies the population buy the product from. As shown in Figure 7, 56% of the target population prefers to buy bricks through a distributor, 26% directly from the manufacturer, 13% in a hardware store, and the remaining 5% from a specialty company.

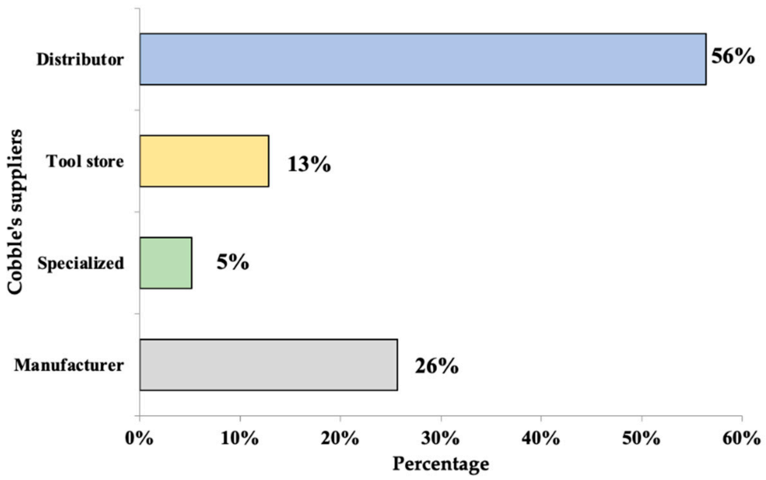

Figure 7. Suppliers of cobbles for pedestrians use in entities interviewed in Ibagué.

According to the above results, companies wishing to manufacture plastic sand bricks should consider within their positioning strategies both direct (manufacturer) and indirect distribution channels (distributors), because results show an increasing inclination of the buyers to purchase through distributors.

This market research also sought to find out what knowledge different entities have about the environmental impact of plastic waste, what actions they take to protect the environment, and whether their business policies consider aspects related to the conservation of the environment. It was found that 58% of the companies do not take any action to reduce plastic waste generation, although 86% of them are aware of the impact it has. On the other hand, the remaining 42% of the market does take steps to reduce it, but most rely on basic recycling such as paper and cardboard recycling. The sector of companies that market products for pedestrian construction does not yet understand the serious inherent impact that exists on the use and subsequent disposal of plastics, which can be caused by the current little or no legislation in Colombia on the management of this waste.

The satisfaction of both, products and suppliers were evaluated (Figure 8). You can see that the market is a little more satisfied with its suppliers than with the products.

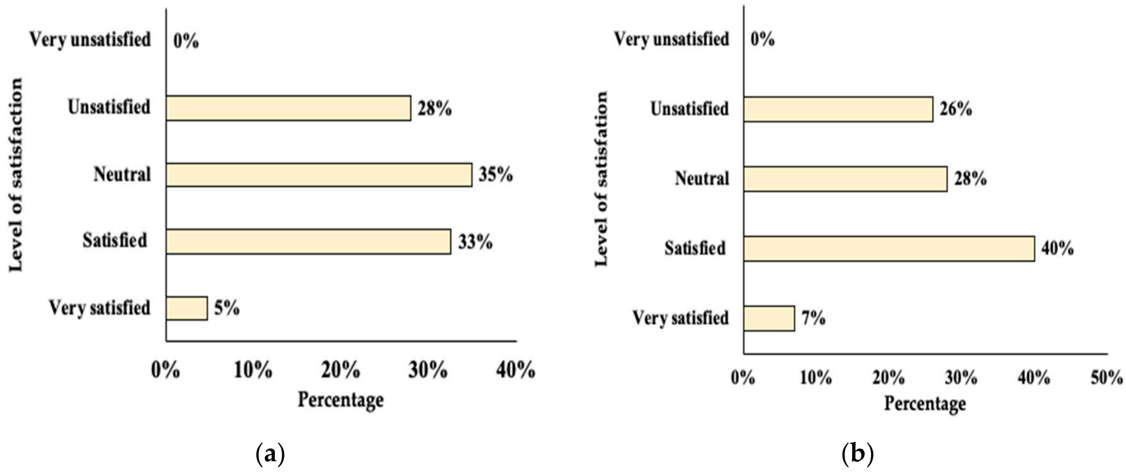

Figure 8. Perception of satisfaction (**a**) with products available in the market and (**b**) with suppliers of the market.

Product dissatisfaction focuses on durability and price. Plastic sand cobbles have a competitive advantage in offering a cobble with a longer shelf life than the materials currently used because of the resistance offered by plastic. However, regarding the price of the product, it should be taken into account whether the market is willing to pay a higher price. Supplier dissatisfaction and neutral opinion remain more than half of the market (54%). About 28% are dissatisfied due to supplier noncompliance and the remaining 22% because of poor quality of the products they offer. Finally, the degree of acceptance of such products on the market was evaded. The results show that 100% of the people surveyed are willing to buy or market unconventional cobbles made of recycled plastic. However, it should be taken into account that only 28% of the market is dissatisfied, so this percentage will be the limiting factor for the competition. The main characteristics by which customers would buy the product are the decrease in environmental impacts when using recycled plastic and the high durability of the product. The survey also showed that 67% of respondents would be willing to pay a higher price for an ecological cobble.

It is important to note that there is a relationship between the lack of knowledge about the environmental damage caused by plastics and whether potential customers would be willing to pay the price for the new plastic sand cobbles. Companies that have no knowledge on environmental issues are not willing to pay a higher price compared to the ones that are accustomed to paying these prices. An estimate of the demand for the potential customers measured in the number of cobbles showed that for the market of the city of Ibagué, 2500 cobbles are projected annually. Bearing in mind the limitations that arise due to market competition (28%), a demand of 1500 cobbles is estimated.

To perform the financial analysis, a cash flow was determined from raw material costs, personnel, indirect manufacturing costs, overhead and financial costs, and investments required for the start-up of the project (Table 4); the values presented in Table 4 are based in the study titled, "Study of the feasibility for the production of non-conventional cobbles using recycled Low-density polyethylene in the city of Ibagué", which is a thesis that was part of the construction of this work [43]. The cost of production was also set at USD 0.59 and with a contribution margin of approximately 25% a sale price of USD 0.74 was set.

Table 4. Five-year projection cash flow for a plastic sand cobbles start-up manufacturing company (in miles of USD).

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Income						
Sales Revenue		438.	454.7	943.2	978.2	1014.7
Total entries		438.4	454.7	943.2	978.2	1014.7
Outcome						
Raw materials		63.1	64.8	133.1	136.6	140.2
Payroll		56.2	58.8	94.6	98.8	109.5
CIF		50.8	52.4	91.8	95.8	100.7
Overhead		32.9	34.0	43.2	45.1	51.6
Financial expenses		9.1	7.7	6.1	4.3	2.3
Depreciation		6.8	6.8	6.8	6.8	6.8
Amortization		0.3	0.3	0.3	0.3	0.3
Total, outcome		219.3	224.8	376.4	388.3	412.2
Profit before tax		219.0	229.9	566.8	590.0	602.4
Income tax		70.1	73.6	181.4	188.8	192.8
Net income		148.9	156.3	385.4	401.2	409.6
Depreciation		6.7	6.7	7.4	7.4	7.6
Amortization		0.3	0.3	0.3	0.3	0.3
Investments						
Fixed assets investments	−76.4			4.1		1.1
Investment in pre-operating	−1.5					
Working capital investment	−32.3					
Capital credit		12.2	13.6	15.2	17.1	19.1
Credit	77.2					
Residual value						83.4
Available balance	**−33.1**	**143.8**	**149.8**	**373.7**	**391.8**	**480.7**

With the values in the table, the net present value (NPV) and the cost-benefit ratio (CBR) were calculated according to Equations (5) and (6):

$$\text{NPV} = [Sd_{year\ 1} * (1+td)^{-1}] + [Sd_{year\ 2} * (1+td)^{-2}] + [Sd_{year\ 3} * (1+td)^{-3}] + [Sd_{year\ 4} * (1+td)^{-4}] + [Sd_{year\ 5} * (1+td)^{-5}] - inicial\ investment, \quad (5)$$

where:

Sd: Cash flow available balance from Investor (Sum of net profit, amortization and provisions)
td: Discount rate (%) (Sum of liability rate and country-risk rate)

$$\text{CBR} = \frac{NPV_e}{NPV_s}, \quad (6)$$

where:

NPV_e: Net present value of revenues
NPV_s: Net present value of expenses

The NPV is approximately $987 USD. This value represents the net cash profit generated during the execution of the project, after the initial investment is covered. Likewise, the cost benefit rate yielded the value of 1.58 in profits for each dollar invested; these indicators show the feasibility of the project as a NPV > 0 and a CBR > 1 were obtained.

4. Conclusions

This study has looked into the use of plastic waste (LDPE) and sand to manufacture cobbles. From the results of the tests carried out for physical properties, plastic sand cobbles showed a decrease in the water absorption rate and its weight by around 50% compared to commercial cobbles from 12.4% to 6.2% and 2.4 kg to 1.2 kg, respectively. Plastic sand cobbles have a compression resistance value of 25.5 MPa which is higher than recommended in the standard, although this value is less than commercial which is 30.6 MPa. Plastic sand cobbles also showed a higher modulus of rupture of 6.03 MPa compared to 16.3 MPa for commercial cobbles which is about three times higher. Both physical and mechanical properties of plastic sand cobbles meet the requirements for Colombian standards. Therefore, this type of cobbles can be installed in areas with light pedestrian and vehicular traffic.

According to the market study conducted to establish a factory for the implementation of processing and transformation of low-density polyethylene (LDPE), the ultimate aim of reducing the problem of plastic waste in the city of Ibague is viable. Additionally, creating an alternative for comprehensive recycling is observed because plastic sand cobbles meet physical and mechanical requirements. In the same way these cobbles meet the current demands in a more sustainable approach. The financial indicators determined that the initial investment would be maximized according to costs, the financial option, and working capital and sales. In addition, the cost profit rate showed a positive value indicating that the project generates surplus funds according to financial projections.

Author Contributions: Conceptualization, L.A.S.-E. and N.J.T.-P.; methodology, L.A.S.-E. and N.J.T.-P.; formal analysis L.A.S.-E. and N.J.T.-P.; investigation, J.E.B.-C., D.F.R.-P., J.G.S.-P.; data curation, J.E.B.-C., D.F.R.-P., J.G.S.-P.; writing—original draft preparation, J.E.B.-C., D.F.R.-P., J.G.S.-P.; writing—review and editing, L.A.S.-E. and N.J.T.-P.; supervision, L.A.S.-E. and N.J.T.-P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Informed Consent Statement: Not applicable.

Data Availability Statement: New data were created or analyzed in this study. Data will be shared upon request and consideration of the authors.

Acknowledgments: The authors appreciate the time enterprises interviewed spent and the technical support in the laboratory procedures provided by laboratory staff at Universidad de Ibague.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Cordier, M.; Uehara, T. How much innovation is needed to protect the ocean from plastic contamination? *Sci. Total Environ.* **2019**, *670*, 789–799. [CrossRef] [PubMed]
2. Rai, P.K.; Lee, J.; Brown, R.J.C.; Kim, K.H. Environmental fate, ecotoxicity biomarkers, and potential health effects of micro- and nano-scale plastic contamination. *J. Hazard. Mater.* **2021**, *403*, 123910. [CrossRef] [PubMed]
3. Ribeiro-Brasil, D.R.G.; Torres, N.R.; Picanço, A.B.; Sousa, D.S.; Ribeiro, V.S.; Brasil, L.S.; de Assis Montag, L.F. Contamination of stream fish by plastic waste in the Brazilian Amazon. *Environ. Pollut.* **2020**, *266*, 115241. [CrossRef]
4. Beaumont, N.J.; Aanesen, M.; Austen, M.C.; Börger, T.; Clark, J.R.; Cole, M.; Hooper, T.; Lindeque, P.K.; Pascoe, C.; Wyles, K.J. Global ecological, social and economic impacts of marine plastic. *Mar. Pollut. Bull.* **2019**, *142*, 189–195. [CrossRef] [PubMed]
5. Rhein, S.; Schmid, M. Consumers' awareness of plastic packaging: More than just environmental concerns. *Resour. Conserv. Recycl.* **2020**, *162*, 105063. [CrossRef]
6. Barnes, S.J. Out of sight, out of mind: Plastic waste exports, psychological distance and consumer plastic purchasing. *Glob. Environ. Chang.* **2019**, *58*, 101943. [CrossRef]
7. Geyer, R.; Jambeck, J.R.; Law, K.L. Production, use, and fate of all plastics ever made. *Sci. Adv.* **2017**, *3*, 25–29. [CrossRef]

8. El Heraldo; Alianza Unicosta. Planeta Plástico 2019. Available online: https://www.elheraldo.co/barranquilla/planeta-plastico-618648 (accessed on 11 November 2020).
9. Superintendencia de Servicios Públicos Domiciliarios Disposición Final de Residuos Sólidos-Informe Nacional 2018. 2019; p. 97. Available online: https://www.superservicios.gov.co/sites/default/archivos/Publicaciones/Publicaciones/2020/Ene/informe_nacional_disposicion_final_2019_1.pdf (accessed on 11 October 2020).
10. Ecos del Combeima Ibagué Seguirá Adelante con el Programa de Reciclaje y Recolección de Basuras 2018. Available online: https://www.ecosdelcombeima.com/ibague/nota-125575-ibague-seguira-adelante-con-el-programa-de-reciclaje-y-recoleccion-de-basuras (accessed on 5 October 2020).
11. Urrutia, C. Qué Retos Enfrenta el Reciclaje y Cómo Podemos Ayudar los Individuos? 2018. Available online: https://sostenibilidad.semana.com/impacto/multimedia/que-retos-enfrenta-el-reciclaje-y-como-podemos-ayudar-los-individuos/42399#:~:text=Colombia%20genera%20anualmente%20más%20de,la%20preservación%20del%20medio%20ambiente (accessed on 8 October 2020).
12. Franco-Urquiza, E.; Ferrado, H.; Luis, D.; Maspoch, M.L. Reciclado mecánico de residuos plásticos. Caso práctico: Poliestireno de alto impacto para la fabricación de componentes de TV. *Afinidad* **2016**, *73*, 575.
13. Goli, V.S.N.S.; Mohammad, A.; Singh, D.N. Application of Municipal Plastic Waste as a Manmade Neo-construction Material: Issues & Wayforward. *Resour. Conserv. Recycl.* **2020**, *161*, 105008. [CrossRef]
14. Parveen, N. UK's Plastic Waste May Be Dumped Overseas Instead of Recycled. *Guard* **2018**. Available online: https://www.theguardian.com/environment/2018/jul/23/uks-plastic-waste-may-be-dumped-overseas-instead-of-recycled (accessed on 3 March 2021).
15. Da Costa, V.; Santos, S.F.; Mármol, G.; Da Silva, A.A.; Savastano, H. Potential of bamboo organosolv pulp as a reinforcing element in fiber–cement materials. *Constr. Build. Mater.* **2014**, *72*, 65–71. [CrossRef]
16. Sanchez-Echeverri, L.A.; Medina-Perilla, J.A.; Ganjian, E. Nonconventional $Ca(OH)_2$ treatment of bamboo for the reinforcement of cement composites. *Materials* **2020**, *13*, 1892. [CrossRef]
17. Sanchez-Echeverri, L.A.; Ganjian, E.; Medina-Perilla, J.A.; Quintana, G.C.; Sanchez-Toro, J.H.; Tyrer, M. Mechanical refining combined with chemical treatment for the processing of Bamboo fibres to produce efficient cement composites. *Constr. Build. Mater.* **2021**, *269*, 121232. [CrossRef]
18. Kim, S.; Hanif, A.; Jang, I.Y. Incorporating Liquid Crystal Display (LCD) Glass Waste as Supplementary Cementing Material (SCM) in Cement Mortars—Rationale Based on Hydration, Durability, and Pore Characteristics. *Materials* **2018**, *11*, 2538. [CrossRef]
19. Suchorab, Z.; Franus, M.; Barnat-hunek, D. Properties of Fibrous Concrete Made with Plastic Optical Fibers from E-Waste. *Materials* **2020**, *13*, 2414. [CrossRef]
20. Appiah, J.K.; Berko-Boateng, V.N.; Tagbor, T.A. Use of waste plastic materials for road construction in Ghana. *Case Stud. Constr. Mater.* **2017**, *6*, 1–7. [CrossRef]
21. Arulrajah, A.; Yaghoubi, E.; Wong, Y.C.; Horpibulsuk, S. Recycled plastic granules and demolition wastes as construction materials: Resilient moduli and strength characteristics. *Constr. Build. Mater.* **2017**, *147*, 639–647. [CrossRef]
22. Santos, J.; Pham, A.; Stasinopoulos, P.; Giustozzi, F. Recycling waste plastics in roads: A life-cycle assessment study using primary data. *Sci. Total Environ.* **2021**, *751*, 141842. [CrossRef] [PubMed]
23. Lonca, G.; Lesage, P.; Majeau-Bettez, G.; Bernard, S.; Margni, M. Assessing scaling effects of circular economy strategies: A case study on plastic bottle closed-loop recycling in the USA PET market. *Resour. Conserv. Recycl.* **2020**, *162*, 105013. [CrossRef]
24. Majumdar, A.; Shukla, S.; Singh, A.A.; Arora, S. Circular fashion: Properties of fabrics made from mechanically recycled poly-ethylene terephthalate (PET) bottles. *Resour. Conserv. Recycl.* **2020**, *161*, 104915. [CrossRef]
25. Lenkiewicz, Z.; Webster, M. Making Waste Work: A Toolkit How to Turn Mixed Plastic Waste and Bottles into Ecobricks a Step-By-Step Guide. 2017. Available online: https://wasteaid.org/wp-content/uploads/2017/10/9-How-to-turn-mixed-plastic-waste-and-bottles-into-ecobricks-v1-mobile.pdf (accessed on 3 March 2021).
26. Mansour, A.M.H.; Ali, S.A. Reusing waste plastic bottles as an alternative sustainable building material. *Energy Sustain. Dev.* **2015**, *24*, 79–85. [CrossRef]
27. Gu, L.; Ozbakkaloglu, T. Use of recycled plastics in concrete: A critical review. *Waste Manag.* **2016**, *51*, 19–42. [CrossRef]
28. Vasudevan, R.; Ramalinga Chandra Sekar, A.; Sundarakannan, B.; Velkennedy, R. A technique to dispose waste plastics in an ecofriendly way-Application in construction of flexible pavements. *Constr. Build. Mater.* **2012**, *28*, 311–320. [CrossRef]
29. Marsh, K.; Bugusu, B. Food packaging-Roles, materials, and environmental issues: Scientific status summary. *J. Food Sci.* **2007**, *72*, R39–R55. [CrossRef] [PubMed]
30. Abraham, J.; Ghosh, E.; Mukherjee, P.; Ganjendiran, A. Microbial Degradation of Low Density Polyethylene. *Environ. Prog. Sustain. Energy* **2016**, *36*, 147–154. [CrossRef]
31. Wilson, D.C.; Webster, M. Building capacity for community waste management in low- and middle-income countries. *Waste Manag. Res.* **2018**, *36*, 1–2. [CrossRef]
32. Kumi-Larbi, A.; Yunana, D.; Kamsouloum, P.; Webster, M.; Wilson, D.C.; Cheeseman, C. Recycling waste plastics in developing countries: Use of low-density polyethylene water sachets to form plastic bonded sand blocks. *Waste Manag.* **2018**, *80*, 112–118. [CrossRef]
33. NTC 2017 Normas Técnica Colombiana Ntc 2017 Adoquines De Concreto Para Pavimento-Metroblock. Available online: https://metroblock.com.co/norma-tecnica-colombiana-ntc-2017/ (accessed on 3 March 2021).

34. Sapag Chain, N.; Sapag Chain, R. *Preparación y Evaluación de Proyectos*; Quinta; McGraw-Hill Interamericana: Mexico City, Mexico, 2008; ISBN 978-956-278-206-7.
35. DANE Clasificación Industrial Internacional Uniforme De Todas Las Actividades Económicas. 2012; p. 496. Available online: https://www.dane.gov.co/files/sen/nomenclatura/ciiu/CIIURev31AC.pdf (accessed on 3 March 2021).
36. Shah, S.N.; Mo, K.H.; Yap, S.P.; Yang, J.; Ling, T.C. Lightweight foamed concrete as a promising avenue for incorporating waste materials: A review. *Resour. Conserv. Recycl.* **2021**, *164*, 105103. [CrossRef]
37. Rama Jyosyula, S.K.; Surana, S.; Raju, S. Role of lightweight materials of construction on carbon dioxide emission of a reinforced concrete building. *Mater. Today Proc.* **2020**, *27*, 984–990. [CrossRef]
38. Akinyele, J.O.; Igba, U.T.; Ayorinde, T.O.; Jimoh, P.O. Structural efficiency of burnt clay bricks containing waste crushed glass and polypropylene granules. *Case Stud. Constr. Mater.* **2020**, *13*, e00404. [CrossRef]
39. Akinyele, J.O.; Igba, U.T.; Adigun, B.G. Effect of waste PET on the structural properties of burnt bricks. *Sci. Afr.* **2020**, *7*, e00301. [CrossRef]
40. Farrapo, C.; Soares, C.; Pereira, T.G.T.; Tonoli, G.H.D.; Junior, H.S.; Mendes, R.F. Cellulose associated with pet bottle waste in cement based composites. *Mater. Res.* **2017**, *20*, 1380–1387. [CrossRef]
41. Arango-Londoño, J.F. Adoquines en concreto: Propiedades físico-mecánicas y sus correlaciones. *TecnoLógicas* **2006**, *16*, 121–137. [CrossRef]
42. CEN BS EN 12467:2004 Fibre-Cement Flat Sheets—Product Specification and Test Methods. 2004, p. 52. Available online: https://shop.bsigroup.com/ProductDetail/?pid=000000000030131889 (accessed on 3 March 2021).
43. Suarez-Puentes, J.G. Estudio de la Factibilidad para la Producción de Adoquines no Convencionales a Partir de la Reutilización del Polietileno de baja Densidad en la Ciudad de Ibagué. Bachelor's Thesis, Universidad de Ibagué, Ibagué, Colombia, 2020. Available online: https://hdl.handle.net/20.500.12313/2314 (accessed on 1 February 2021).