Studies on the durability of plastic pavers tested on a roadway in the city of Kinshasa in the DRC

Abstract

Objectives: In the City of Kinshasa, most of the roads are unpaved and public transport poses enormous problems. This study, carried out with the assistance of the Office of Roads and Drainage (OVD), experiments with the adaptation of paving stones resulting from the recycling of thermoplastic waste following the formula defined by the Laboratory of Biotechnology, Technology and Environmental Microbiology (LBTME) of the University of Kinshasa for the production of good paving stones: 65% fine sand against 35% thermoplastic waste.

Research design: The study is subdivided into six parts: introduction, study environment, materials and methods, results, discussion and conclusion.

Location and duration: The study was carried out on the section of Belgika street between Kabambare and Croix-rouge streets/municipality of Barumbu/city of Kinshasa from April 2, 2012 to June 7, 2020.

Methodology: We carried out three tests: resistance, test board and adhesion. We also carried out an investigation targeting local residents and the OVD authorities.

Results: The Resistance Test: 13 N/mm², a better average value compared to the pavers stored at the OVD (10 N/mm²). This strength value is crucial for understanding the behavior of materials under different loads, which is essential for the design and analysis of structures in engineering. Testing the test boards: good adaptation of the pavers without breakage, otherwise some disturbances in certain places due to the sagging of the foundation layer and the frame edges. The grip test carried out at an average speed of 85 km/h for an average braking distance of 7.3 m did not break any blocks.

Conclusion: It is demonstrated that plastic pavers have shown their durability and importance for the construction of secondary and tertiary roads in the City of Kinshasa compared to bitumen and concrete and therefore deserves particular attention.

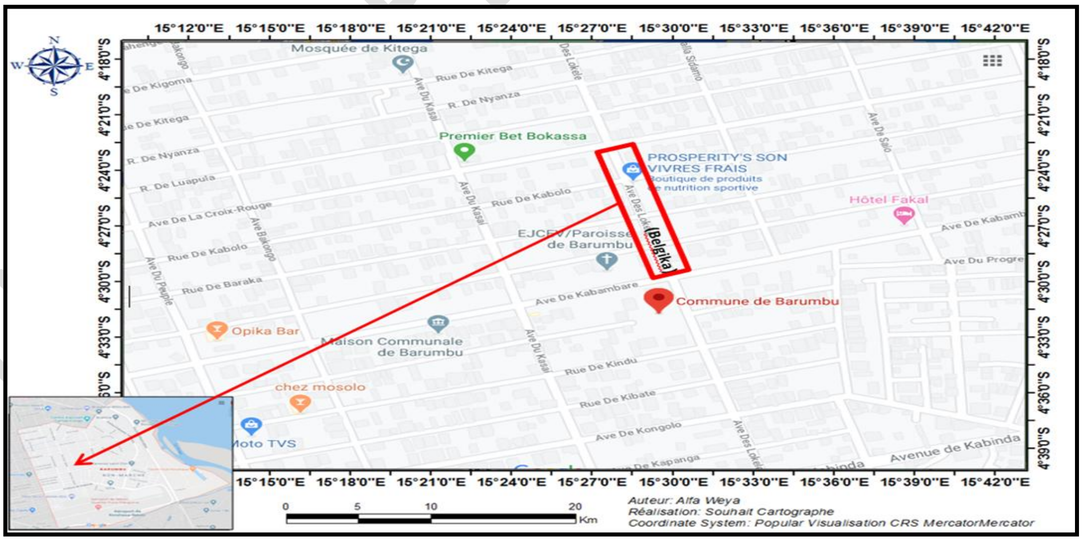
Key words: Sustainability, plastic pavers, pavement, Belgika street, Kinshasa city.

1. Introduction

In most municipalities in cities in developing countries, 90% of products and items purchased in public markets, grocery stores, shops and stores are packaged in plastics which are thrown away without standards after use, in urban spaces [1]. For the city of Kinshasa, this practice encourages the disorderly dispersion of plastic waste in the streets, gutters, public spaces, waterways, etc. [2]. This then results in unfortunate consequences for the environment and health: flooding due to water disinfiltration, deterioration of public spaces, proliferation of non-sanitary raw landfills that generate disease vectors [3]. Due to the fact that the life cycle of an object including all stages from the extraction of natural resources, through manufacturing, packaging, distribution, consumption or use of product or service until its Final disposal remains today a major problem not mastered by the majority of municipalities in developing countries [4], the questions asked were whether the recycling of low and high density thermoplastics in manufacturing plastic pavers, would produce materials suitable for road construction. In addition, if the various tests (resistance, test board and adhesion) on the paving stones laid on Belgika street after 8 years of wear would give results that would be of interest to urban services. From the above, it is likely that the recycling of post-use thermoplastics would produce construction materials (pavers) best suited to the construction of roads. These blocks would continue to maintain good resistance values and would respond better to grip shocks over a period of at least two years of wear recommended for the test board test.

2. Study environment

The study environment for this research is the section of Belgika street, 187 m long and 7 m wide, located perpendicularly between Kabambare street to the East and Croix-Rouge street to the West in the Mozindo district, Barumbu municipality in Kinshasa city (figure 1).



Legend : [red rectangle] : Study area

Figure 1. Location of Belgika street (Kabambare & croix-rouge section)

3. Material and Methods

It was carried out: - a pre-investigation along the relevant section of Belgika street to gather some opinions from local residents and observe the condition of the paving stones on the roadway; - the resistance test of the paving stones at the National Public Works Laboratory of the Roads Office, located on 482 De la Science street in Kinshasa/Gombe. It consisted of determining for the paving stones stored at the OVD and those placed on the roadway: the dimension, weight, density, degree of compression, the maximum load observed at rupture in the pressure gauge of the “press” device control” brand Controls Milano Itali (figure 2).

The total breaking stress was determined by the following formula:

$$\text{Total rupture counterforce (in kg/cm}^2\text{)} = \frac{\text{Breakdown charge}}{\text{Total compressed surface}} \quad [5]$$

- The test board test carried out in situ on ±1/3 (187 m/703 m) of the roadway: It took into account the duration of exposure of the paving stones since the date of their installation (February 14, 2012) until the test date (July 6, 2020) in order to evaluate the adaptation of the pavers to different uses and bad weather for at least 2 years as recommended by [6]. - The adhesion test which was carried out by jostling when braking a 4 speed Hyundai bus (60, 80, 100 and 100 km/h) in order to observe the reaction of the paving stones; - Surveys carried out from mid-May to mid-July 2020 with 37 residents of the study section, 44 Agents and 9 OVD Authorities. For the latter, it was a question of knowing, among other things, the date of the laying of the paving stones, namely February 14, 2012; - The processing of survey sheets and the processing of data carried out by computer software: Spss, Stata 12 and Excel.

Figure 2. Image of the machinery
« Controls Milano Itali »

4. Results

4.1. Resistance test

4.1.1. Numerical values of resistance test parameters

Table 1. Average numerical values of stress test parameters

Parameters	Measurement of resistance of pavers		
	At the beginning of manufacturing	Stored to the OVD	Spread over Belgika street
Settings Date	13/02/2010	13/02/2010	13/02/2010
Test Dates	17/02/2010	06/07/2020	06/07/2020
Age on 06 july 2020	4 days	10 years 4 months 22 days	10 years 4 months 23 days
Date of laying of paving stones on Belgika	-	-	14/02/2012
Duration of laying paving stones in Belgika	-	-	8 years 4 months 22 days
Thickness (cm)	8±2,43	7,6±1,22	7±1,61
Volume (cm^3)	2772±95,63	2400±190,58	2400±239,72
Weight (gr)	4805±195,85	4314±535,57	3644±176,78
Density (gr/cm^3)	1,73±1,62	1,80±2,14	1,52±2,51
Total compressed surface (Cm^2)	396±42,59	300±32,19	300±32,19
Breaking load (Kg)	35200±2193,93	29000±1609,91	40000±7377,51
Simple breaking stress (Kg/cm^2)	89±16,00	97±16,01	133±6,08
Total breaking stress (N/mm^2)	9±6,08	10±16,09	13±6,08

Table 1 shows that compared to the pavers stored at the OVD, those laid on Belgika street for 8 years 4 months and 22 days showed a better average value of resistance, i.e. 13 N/mm^2. This average value which reflects the durability of the paving stones (8 years 4 months and 22 days) is higher than the two others found at the start of manufacturing (i.e. 9±6.08 N/mm^2) and that of the paving stones stored at the OVD (i.e. 10±16.09 N/mm^2). It therefore shows the importance of plastic pavers in road construction in Kinshasa city.

4.1.2. Reaction of paving stones subjected to resistance test

Pavers before compression

Pavers under compression in machine

Pavers after compression

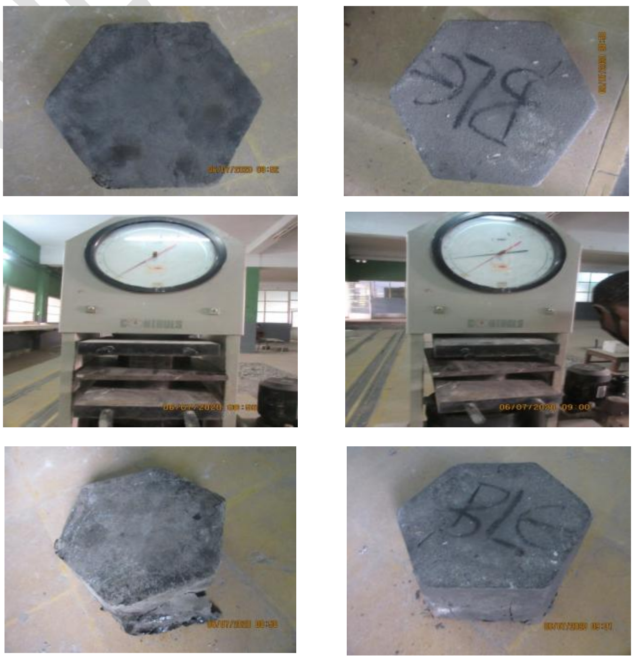


Figure 3. Reaction of pavers subjected to resistance testing

From this figure, it shows that on the pressure gauge, the pavement block with a higher breaking load (i.e., 40000 kg) experienced less deformation compared to that which was stored at the OVD (i.e., 29000 kg).

4.2. Test board test of paving stones on Belgika street

4.2.1. Reaction of paving stones subjected to the test board test

Figure 4. View of the paving stones at the start of installation (1) and after 8 years (2)

It is observed that during 8 years of wear and tear under various traffic tractions, no paving stone was seen broken, only a few unevenness of the paving stones due mainly to some slight sagging of the foundation layer.

4.2.2. Deterioration statistics for paving stones subjected to the test board test

Table 2. Cobblestone statistics after 8 years, 4 months and 22 days.

Types of pavers	Absolute frequency	Relative frequency	Number of m²
Damaged (broken) pavers	0	0,0	0
Taken cobblestones	123	0,3	4
Pavers, remaining in place	36285	99,7	1134
Total	36408	100,0	1138

It is observed that on 100% of the paving stones (i.e., 36408 paving stones which is equal to 1138 m²), there were no paving stones destroyed; 99.7% of the paving stones (i.e. 36,285 paving stones which is equal to 1134 m²) remained in place and only 0.3% (i.e. 123 paving stones which is equal to 4 m²) were taken away or are out of place following the dilapidation of the framing borders as observed in figures 5.

Figures 5. View of dilapidation of the framing edges

4.3. Test of adhesion of cobblestones on Belgika street

4.3.1. Mathematical evaluation of adhesion test parameters

Table 3. Measurements of parameters related to the adhesion test

Number of races	Speed (Km/h)	Braking Distance (m)	Reaction of the paving stones
1	60	4,5	Black mark, no broken pavement
2	80	6	Black mark, no broken pavement
3	100	9	Black mark, no broken pavement
4	100	9,6	Black mark, no broken pavement
Average	85	7,3	-

The results show that with an average of 85 km/h of the 4 gears engaged (60, 80, 100 and 100 km/h) and an average distance of 7.3 m of 4 braking times (4.5, 6, 9 and 9.6 m), no paving stones were broken, except for black marks from tires rubbing on the paving stones.

4.3.2. *Reaction of paving stones subjected to the adhesion test*

Rear view of the machine braking

Profile view (in gros) of the machine in full braking

View profile of engine brake traces

Close view of the engine brake traces

Figures 6. View of the reaction of the pavers subjected to the adhesion test

There are only black marks resulting from the traction of the tires on the cobblestones; This translates into the fact that the cobblestones have adhered perfectly to the jostling of the vehicle's braking.

4.4. Results of investigations

4.4.1. Socio-demographic aspects: distribution of respondents depending on the function

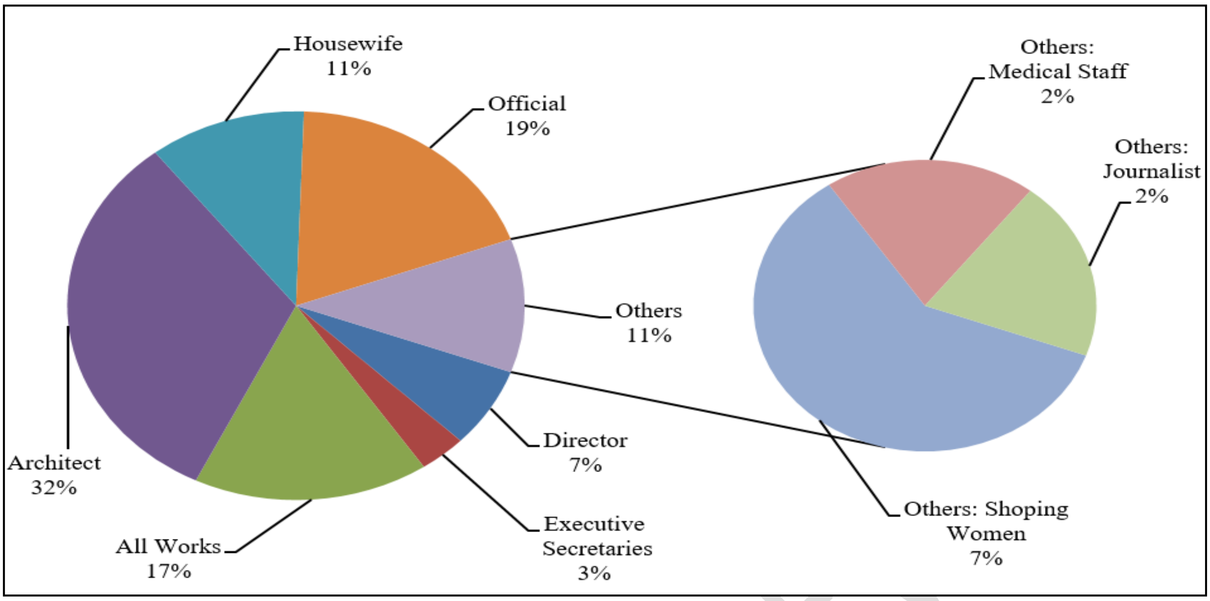


Figure 7. Distribution of Respondents according to function

According to the function of the respondents, the Architects of the OVD (32%) are in the majority than the State civil servants (i.e. 19%). They are followed by "All Works (TT) of the OVD (i.e., 17%) and Housewives (i.e., 11%).

4.4.2. Aspects relating to the use of paving stones and the paving of Belgika street

Table 4. Distribution of respondents according to the opinion to put paving stones on all the roads in Kinshasa and the use of plastic paving stones compared to bitumen.

Variables	Modality	Absolute Frequency	Relative Frequency
Is the recycling of plastics into other plastic materials beneficial for the population?	Yes	90	100,0
	No	0	0,0
	Total	**90**	**100,0**
If yes, in what way?	Job creation	39	43,3
	Sanitation	44	48,9
	Promotion of local initiatives	3	3,3
	Financial giving	4	4,4
	Total	**90**	**100,0**
Considering these paving stones, what is your opinion on the use of plastic packaging?	Continuous use	84	93,3
	Stopped using	6	6,7
	Total	**90**	**100,0**
What is your opinion if these plastic paving stones should be put in all the roads in Kinshasa?	Good	90	100,0
	Bad	0	0,0
	Total	**90**	**100,0**
What is your impression of the use of plastic paving stones in roads compared to bitumen?	Plastic pavers are good	90	100,0
	Bitumen is good	0	0,0
	Total	**90**	**100,0**

From this table, 100% of respondents find the recycling of plastics beneficial for the production of other plastic materials, because it cleans up the environment (48.9%), creates jobs (43.3%), provides added value (4.4%) and promotes local initiatives (3.3%). In addition, 93.3% of respondents support the continued use of plastic packaging compared to 6.7% who denounce it. It is also noted that 100% of respondents, on the one hand, wanted to see all the roads in Kinshasa covered with plastic paving stones and on the other hand, chose the use of plastic paving stones as the best material for covering roads compared to asphalt.

Table 5. Distribution of respondents according to their appreciation of plastic pavers compared to concrete pavers

Variables	Modality	Absolute Frequency	Relative Frequency
How do you rate plastic pavers compared to concrete pavers?	Excellent	45	50,0
	Good	37	41,1
	Good enough	8	8,9
	Total	**90**	**100,0**
For what ?	Are durable and of good resistance	59	65,6
	Fix multiple issues	21	23,3
	New technology in the country	10	11,1
	Total	**90**	**100,0**

It is shown that 50% of those surveyed appreciate plastic pavers more highly than concrete pavers; 41.1% of respondents simply think that plastic paving stones are good and 8.9% find them quite good. Whether for this or that other assessment, the durability and good resistance of plastic paving stones defended mainly by 65.6% of respondents remain firstly the argument which supports these assessments, then comes the argument according to which paving stones plastics solve several socio-economic problems (sanitation, income, employment, etc.) (i.e., 23.3%) and ultimately, plastic paving stones constitute a contribution of a new technology to the country (i.e., 11.1%).

Table 6. Impressions of the Respondents on the plastic paving stones placed on Belgika street

Variables	Modality	Absolute Frequency	Relative Frequency
Are you satisfied with the paving stones on your street?	Yes	37	100
	No	0	0
	Total	**37**	**100**
Why ?	End the flood	7	19
	Beauty of the street	9	24
	Very resistant pavers	21	57
	Total	**37**	**100**
What impact does paving your street with plastic paving stones have on daily life?	Improvement of living conditions and the environment	16	43
	Intensification and improvement of commercial activities	13	35
	Valuation of commercial houses and rent	8	22
	Total	**37**	**100**

He indicates that 100% of local residents are satisfied with the installation of plastic paving stones on Belgika street, because 57% rely on the resistance of the paving stones, 24% see the architecture of the paving stones, and 19% noted the end of the increase in flooding in their neighbourhood. The benefits that paving the street brings to daily life are: improvement of living conditions (i.e., 43%), intensification and improvement of commercial activities (i.e., 35%) and enhancement of houses. commercial and rent (i.e., 22%). The benefits that paving the street brings to daily life are: 43% of respondents noticed the improvement in living conditions and the environment in their neighbourhood, 35% noted the intensification and improvement commercial activities and 22% simply recorded the valuation of commercial houses and rent.

5. Discussion

The results found from the tests of: resistance (i.e. 13 N/mm^2), test board and adhesion of the plastic pavers coated on Belgika street and resulting from the recycling of thermoplastic waste at a proportion of 35% of low thermoplastic waste density against 65% of the average river sand, as required by the LBTME are conclusive.

These proportions are those also indicated by [7] who states that the ideal proportions for making paving stones of better resistance are 65% sand and 35% thermoplastic waste. The above also translates the physical law which says that: when the deformation surface of a material is linear, the coefficient of proportionality called spring stiffness noted $k: F = k1 \cdot \Delta l$ for traction-compression is largely dependent on the proportions of the materials that make up this material [8].

This is why [9] noted that the proportions of materials should not be neglected in the manufacture of plastic construction materials with good resistance values.

If the proportions of the materials are not to be neglected, it is the same for the quality of the plastics to be used, which is also one of the major parameters for the success of recycling, which is why the OVD has chosen only low-density thermoplastics. That is why, from the above, [10] in this doctoral research found that low density thermoplastic is more suitable than mixed plastic in terms of polymer structure due to its ability to be melted and reshaped several times without losing its properties. Unlike mixed plastic, which is made up of different types of plastics mixed together, low density thermoplastic is a specific type of polymer that has a linear or branched molecular structure that allows it to have a high molecular mobility, which mobility facilitates its fusion and its molding around relatively low temperatures. This is observed by [11] who points out that when plastic waste of different types is mixed, recycling encounters incompatibility problems since processing temperatures are different. Thus, [12] points out, the mixing of several plastics leads to a decrease in the quality of the mechanical characteristics of the final product. Despite the above, [13] finally analyzed that the procedure followed for the recycling of plastic waste is decisive in the quality of the final product or states [14] that the choice of good quality materials and equipment adapted for the manufacture of road construction materials is essential in the resistance of the board to multiple eventualities. The justifications put forward above demonstrate the test board test result of the paving stones of the Belgika street roadway, which have not suffered any significant deterioration.

In comparison with the resistance values of the pavers at the beginning of manufacture (i.e., 9 N/mm^2) and those of the pavers stored at the OVD (i.e., 10 N/mm^2), it can be seen that the value of the resistance of paving pavers (i.e., 13 N/mm^2) is higher. This can be justified by the fact that, these paving stones have undergone for 8 years, the pre-compressions due to the different load constraints of the passage of people, machines, motorcycles and therefore, have adhered to better resist the jostling of braking (Grip Test) of the Machinery used for this purpose. The above can be supported by the results of [15] and [16] who found that the physico-climatic parameters (compaction, temperature, consolidation of the material, breaking load, corrosion, time, etc.) can actively contribute to increasing the resistance of building materials. This is also approved by [17] who says that a road construction material subjected to different compressions and climatic hazards always ends up consolidating more because having been subjected to pressure from the load of traffic it supports for a time. The results of the surveys found that recycling plastics into other materials is beneficial to the population because it cleans up the city (48.9%), creates jobs (43.3%), improves living and environmental conditions (43%), intensifies and improves commercial activities (35%). It is true that plastic materials are easily integrated into the classic road construction process and to this end constitute the roadmap to the circular economy for construction materials [18]. This is why several authors present other advantages of using plastic materials for road construction compared to bitumen. We can cite: [19] who supports the Dutch company KWS which is developing a new way of building roads using 100% recycled plastic, arguing that the lifespan of a plastic road would be multiplied by three compared to its asphalt counterpart and the quantity of work carried out each year on the roads would be reduced, both in frequency and duration; [20] who found that, typical road construction materials, on average, need to be replaced every 10 to 15 years while requiring regular annual maintenance to maintain appropriate safety standards, while these pavers as observed most recently as of October 6, 2023 are still without catastrophic failure or similar anomalies with the observations of the date of the test carried out on July 6, 2020; [21] and [22] who found that thanks to the concept of prefabrication, the installation of plastic pavers on sand or on lower quality soil can lead to better control of the quality of the road. during the construction process and therefore requires less energy; [23] which states that synthetic plastic roads would be more durable than their asphalt counterpart, in particular because they have better thermal resistance over a wider temperature range (from -40 to +80°C). [23] adds that holes cannot form in the road either and thanks to the modularity, the portions which would still be damaged could be replaced more quickly; Compared to the study conducted by [24] on "Exploitation of plastic bags in roadway blocks. Materials Today: Proceedings", which found that the accumulation of bagasse ash improves the lifespan of the design compared to the usual design in properties substituted for cement of approximately 5 to 7 years; Instead, our research extended the lifespan of the pavement by up to 11 years.

All of the above statements from the Authors justify the results of the surveys where 93.3% of respondents demand the continued use of plastic packaging and 60% suggest the creation of a plastic recycling industry including their use could also enable a certain number of other innovations such as energy production and ultra-quiet roads and sustainable.

6. Conclusion

This research aimes to study the sustainability of road infrastructures using self-locking plastic pavers as base materials, which come from the recycling of post-use thermoplastics. Following the results obtained on the quality of these paving stones after 8 years of wear on the roadway of Belgika street and the surveys carried out among the OVD staff and the inhabitants of this road, it is necessary to conclude the following: the recycling of post-use thermoplastics which abound in the Kinshasa city in the manufacture of paving stones for road construction is of great importance because: - The difference in the resistance values of the paving stones 4 days after manufacturing (i.e., 9 N/mm²) and at 8 years, 4 months and 22 days after their installation on the roadway of Belgika street (i.e., 13 N/mm²) mm²) demonstrated their adaptation in road construction in Kinshasa. This last resistance value (i.e., 13 N/mm²) is encouraging for the success of the test board test evaluated after 8 years, i.e. 4 times longer compared to the minimum duration of 2 years (recommended) of traction on the roadway of Belgika street. - The adhesion test carried out when braking the machine only confirmed the greater effectiveness of plastic pavers for road construction because no negative effect was observed on the pavers subject to tire corrosion. - All respondents (100%) supported seeing all the roads in Kinshasa built with plastic pavers and confirm their use as the best road construction material compared to bitumen and concrete.

Therefore, there is reason to recommend the use of plastic pavers for the construction of secondary and tertiary roads in Kinshasa because they adapt better than bitumen and concrete. The recycling of plastic waste as a real opportunity for the circular economy can contribute to the sanitation of the Kinshasa city in the face of plastic pollution.

References

1. Kassay Ngur-Ikone Jules, 2015. Plastic waste management in Kinshasa: another environmental challenge to address in the design of sustainable cities. Environment, climate change and food security. In social analysis laboratory in Kinshasa. (LASK), Vol. IX, Single issue, January-April. Indd 131. 24p.
2. Vuni Simbu Alexis, Holenu Mangenda Holy, Puela Puela Fidel, Lelo Nzuzi Françis, Kinsungila Wamba Elvis, Aloni Komanda J.K. and Tshibuabua Mutayiya Faustin, 2018. Study of the current management of urban waste in Kinshasa by observation along the university road. University of Kinshasa, Fac. of Sciences, Dept. des Géosciences, B.P. 190, Kinshasa XI, D.R. Congo. 15p.
3. Holenu Mangenda Holy, Mulaba Pius and Kiawutua Alfred, 2020. Household waste management in the city of Kinshasa: Survey on residents' perceptions and proposals. In Waste Sciences and Technology-No.83-March 2020. Geosciences/University of Kinshasa. 8p.
4. Imbeault-Tétreault Hugues, Maude Menard-Chicoine, Alexandre Milovanoff, Julien Walzberg, Valérie Patreau, Renée Michaud, 2015. Brief submitted as part of the evaluation of the issues and impacts of the ban on single-use shopping bags in retail stores in the city of Montreal. Permanent commission on water, the environment, sustainable development and large parks. International reference center on the life cycle of products, processes and services (CIRAIG). University of Quebec in Montreal. 17p.
5. Dreux Georges, 1981. New concrete guide. 3rd edition EYROLLES. Paris. 307p.
6. Duriez, M. and Arrambide, J., 1962. New treatise on construction equipment. Volume II. 2nd edition. DUNOD. Paris. 1367p.

7. Brahiman Traore, 2018, Development and characterization of a composite structure (sand and recycled plastic waste): Improvement of resistance by clay fillers. Materials. Burgundy Franche-Comté University; Félix Houphouët-Boigny University (Abidjan, Ivory Coast), French. ffNNT: 2018UBFCA029f. 127p.
8. Pommier Sylvie, 2017. Materials: Mechanics of materials. Applied sciences in physics and engineering for research and teaching. SAPPHIRE. Paris-Saclay Normal School. Paris-Saclay University. 155p.
9. Sandoumbé Triaw, 2006. Mechanistic-empirical sizing of road structures: application to the Séo-Djourbel section. End-of-studies project with a view to obtaining the Design Engineering Diploma. Polytechnic Higher School: THIES Center, Department of Civil Engineering. Cheikh Anta Diop University of Dakar/Senegal.104p.
10. El Boust Ani Meriem, 2016. Modification of plant fibers by an ecological process: effects on microstructure and compatibility with polymeric matrices. Thesis under joint supervision. Cadi Ayyad University (Marrakech) and University of Quebec A Trois-Rivières,: Discipline: Sciences and Techniques, Specialty: Sciences and Engineering of Lignocellulosic Materials (Canada). 229p.
11. Turlan Tristan, 2013. Waste: collection, treatment, sorting, recycling. 2d. Dunod, Paris, ISBN 978-2-10-058531-1. 211p.
12. Sandrine Ausset, 2013. Process for recycling abs-pc mixtures from waste electrical and electronic equipment (WEEE). Thesis presented at Bordeaux 1 University. Doctoral School of Physical Sciences and Engineering. Specialty: Mechanics. 315p.
13. Colin Jacob – Vaillancourt, 2018. Advanced characterization and valorization of mixed post-consumer plastics. Case study at Gaudreau Environnement Inc. Master's degree in civil engineering, Master of Science (M Sc), University of Laval, Quebec Canada.110p.
14. Anonymous, 2018b. Review of urbanization in the Democratic Republic of Congo: Productive and inclusive cities for the emergence of the Democratic Republic of Congo. World Bank. Development Directions. Washington, DC: DOI: 10.1596/978-1-4648-1205-7. License: Creative Commons Attribution CC BY 3.0 IGO.97p.
15. Abderrahmane Soufi, 2013. Study of the durability of reinforced concrete systems: repair mortars in a marine environment. Thesis To obtain the degree of Doctor from the University of La Rochelle. Discipline: Civil engineering. Doctoral School: Sciences and Engineering in Materials, Mechanics, Energy and Aeronautics (SI-MMEA). 235p.

16. Ndzana Akongo Grégoire & Tchoumi Samuel, 2007. Rehabilitation of reinforced concrete structures damaged by corrosion of the reinforcements. Online memory. University of Douala (Ecole Normale Supérieure de l'Enseignement Technique) ENSET - DIPET2 (Diploma for Teachers of Technical Education High Schools 2nd grade) Civil Engineering, Option: Building and Works. 104p.
17. Gilles Grondin, Denis Lessard, Maude Boucher and Michel Poulin, 2012. Guide for the study and construction of road embankments on peatlands. Roads laboratory management: Geotechnics and geology department. Transports Québec.56p.
18. Bernard Perret, 2014. The circular economy, current situation and perspectives. Report No. 009548-06. General Council for the Environment and Sustainable Development. Ministry of Ecology, Sustainable Development and Energy. French Republic. 88p.
19. Carole de Fays, 2015. Building roads with recycled plastic. Belgium. The social media of buildings and sustainable cities. Construction 21 Belgium. 3p.
20. Coutu, Ronald A. Jr.; Newman, David; Crovetti, James; Mishra, Ashish Kumar; Munna, Mohiuddin; Delbridge-Ramos, Allyssa; Brusaw, Julie; and Brusaw, Scott, "Testing Photovoltaic Pavers for Roadway Applications" (2019). Electrical and Computer Engineering Faculty Research and Publications. 597.
21. Aleyda Resendiz-Vazquez, 2011. The industrialization of buildings: the case of prefabrication in school construction in France (1951-1973). Thesis with a view to obtaining the degree of doctor in History of Technology and the Environment. National Conservatory of Arts and Crafts. Center for the History of Technology and the Environment. French Institute of Urban Planning, University of Marne-la-Vallée. 468p.
22. Anonymous, 2018a. Technical rules for road construction in African countries in the intertropical zone. (Studies, design, construction, maintenance). Version incorporating the entire 1980 guide Supplemented by the BCEOM manual from 1972/1984. African Association of Building and Public Works Laboratories (ALBTP) Transnational Committee of Geotechnical Engineers of Africa (CTGA). 643p.
23. Michelin, 2016. The MICHELIN group's innovation strategy for sustainable mobility. Press kit. 36p.
24. Dasarathy AK, Selvi MT. Exploitation of plastic bags in roadway blocks. Materials Today: Proceedings. 2021 Apr 24.