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FACULTY OF ENGINEERING

Suitability of Plastic Paving Blocks for Construction of Non-Motorised Transport Facilities

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BSc. Civil Engineering (JKUAT)

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DEDICATION

To my late dad, Mr. Peter Muigai Kiongo for ensuring I never lacked anything in my journey towards being a Civil Engineer. You endeavored to make sure I had the stepping stone I needed for me to attain my education and intellectual development.

To my mum, Mrs. Pauline Muigai and Siblings Mugure, Wanjiku, Kiniti and Kiongo Muigai for the continued support you gave me during this journey. You did not hesitate to lend a helping hand and your endless encouragement ensured I completed the course.

You are all greatly loved and cherished.

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Special thanks to Corec Kenya for providing me with the sample required for the study and SGS for providing me with lab facilities where I undertook the tests.

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Last but not least, I thank God for His grace, strength and sustenance during my studies.

ABSTRACT

Walking remains the oldest and most common mode of transport making up a portion if not most or all of our daily commute. However, there is inadequate infrastructure within our urban centres to cater for the pedestrian volumes experienced because most of the transport infrastructure developments in our urban areas have a bias towards motorised transport. This has led to pedestrians and cyclist being the most affected in road accidents; inadvertently leading to them been categorised as vulnerable roads users. The world is currently producing 300 million tonnes of plastic waste with Kenya contributing 407,506 tonnes per year, and with increasing population, urbanisation and development; the annual plastic waste produced shall continue to increase. Due to widespread littering, plastic waste has become a common sight in our urban and rural areas and the non-biodegradability of plastic makes proper disposal of plastic waste a menace. Asphalt and concrete, which are the conventional materials used for the construction of the walkways and cycle lanes, are most ideal for the motorised transport pavements and can prove to be expensive for use in low volume pavements. The influx in plastic waste in our society, could make plastic paving blocks a suitable alternate construction material that can be affordable, readily available and environmentally friendly if adopted. This study assessed the suitability of plastic paving blocks for use in the construction of walkways and cycle lanes; by determining their physical and mechanical properties, and undertaking a purchase cost analysis on samples provided by Corec Kenya. The plastic paving blocks are manufactured by mixing sand with red oxide. This mixture is mixed with shredded plastic at a temperature between $140^0 – 170^0$ c. The physical and mechanical properties tested in this study were total water absorption rate, tensile strength and abrasion rate in accordance with South African National Standards - SANS 1058:2021. All properties investigated were within the recommended specifications in SANS 1058:2021. The purchase cost of one square meter of plastic paving block was compared to that of concrete paving blocks and it was determined plastic paving blocks are 40¢ more costly. However, the impacts the use of plastic waste has on environmental pollution negates this. Based on these findings, this study recommends that plastic paving blocks are suitable for use in construction of Non-Motorised Transport Facilities.

Key words: *Non-Motorised Transport, Plastic waste, water absorption rate, strength, abrasion rate, recycling,*

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ABBREVIATIONS

BRT – Bus Rapid Transit

CBD – Central Business District

Corec – Continental Renewable Energy Company Limited

FHWA – Federal Highway Administration

INTP – Integrated National Transport Policy

IRC – Indian Roads Congress

ITE – Institute of Transportation Engineers

Kes – Kenya Shillings

KNBS – Kenya National Bureau of Statistics

MPa – Megapascals

NMT – Non-Motorised Transport

NIUPLAN – Nairobi Integrated Urban Development Master Plan

UNEP – United Nations Environment Programme

USD – United Stated Dollar

RHS – Right Hand Side

SANS – South African National Standards

SMDUAK – Street Design Manual for Kenyan

CHAPTER 1 INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Non-Motorised Transport (NMT) also known as active or human-powered transport is defined as all forms of travel that do not rely on an engine or motor for movement. It includes walking, cycling, wheel chair and small-wheeled transport such as hand carts, skates, push scooters and skateboards (Mat et al, 2011). In Nairobi, walking is the most dominant mode of transport accounting for 47 per cent of trips in the modal split (NIUPLAN 2014) as highlighted in Figure 1-1. However, most transport infrastructure developments focus on providing for motorised transport more specifically private vehicles that account for only 15 per cent of the trips neglecting pedestrians the majority in the modal split.

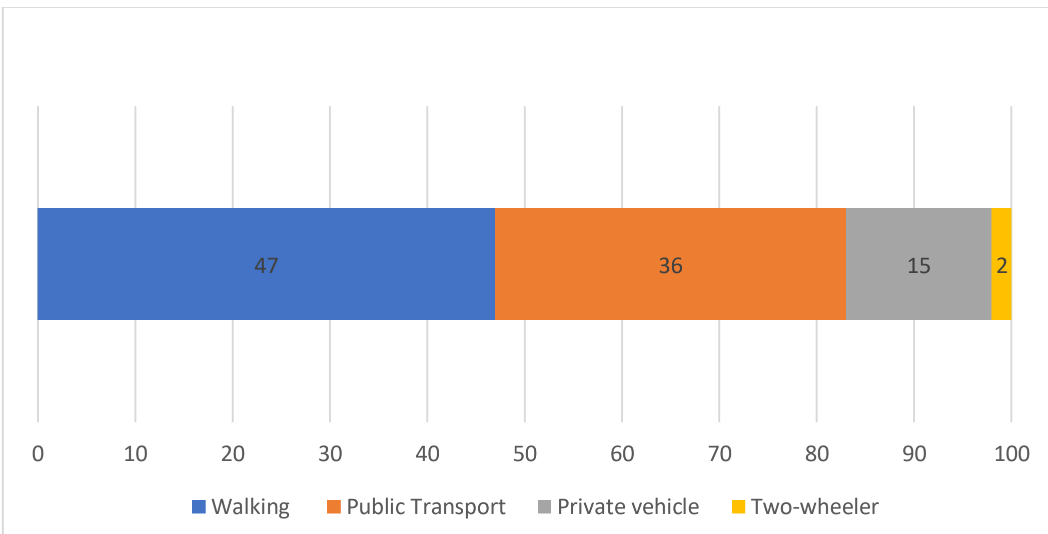


Figure 1-1:Modal Split Nairobi; 2004

(Source: NIUPLAN 2014)

This is evident in Plate 1-1 of down-town Nairobi with limited non-motorised transport infrastructure despite the area having a high pedestrian traffic volume forcing pedestrians to compete with motorised vehicles. This results to numerous conflicts that endanger the non-motorised transport user since they are forced to walk on the carriageway; space provided for motorised transport.

Plate 1-1:Inadequate NMT facilities, Downtown Nairobi

(Source: The Nairobi Decongestion Taskforce Report, 2014)

It is important to note that virtually everyone is a pedestrian at one point of their trip because even people relying on either public or private transport for their movement have to walk for a portion of their trip for the first and last mile making Non-Motorised Transport (NMT) an integral element of urban transport within the city (Todd, 2009). The absence of proper NMT infrastructure such as walkways and cycle lanes has led to pedestrians and cyclists being the most affected by road accidents and inadvertently leading to them been categorised as vulnerable roads users.

The widespread littering experienced in our urban and rural areas has made plastic waste a common sight in our communities. The world is today producing 300 million tonnes of plastic waste with Kenya contributing 407,506 tonnes per year (UNEP, 2022) and with increasing population, urbanisation and development the annual plastic waste produced is bound to increase. The non-biodegradability property of plastic makes proper disposal of plastic waste a menace. It is believed that plastics remain on earth for 4,500 years without degeneration endangering the environment and all life forms (Amit,2012).

The Ngong dumpsite pictured in Plate 1-2 (Lewis, 2018) represents the situation of most dumpsites across the country where most of the waste generated is categorised as plastic waste. Only 9 per cent of plastic waste is recycled the vast majority of the rest accumulates in landfills or the natural environment (UNEP, 2022). A complete ban of use of plastic is not feasible despite the negative effects discussed above as every industrial sector; agriculture, automobile, packaging and building construction has embraced plastic usage because of its versatility and cheap large-scale production (Amit, 2012). Therefore, avenues of reuse and recycling of plastic should be explored to reduce its impact on the environment.

Plate 1-2: Improper Disposal of Plastic Waste, Ngong Dumpsite
(Source: Lewis, 2018)

The plastic problem has given rise to small enterprise companies that recycle plastic waste into building materials such as fencing poles, roofing tiles, and paving blocks. One of the companies founded in 2015, Continental Renewable Energy Co. Ltd reports that it has so far ensured that 700 tons of plastic waste is recycled and, in the process creating hundreds of employment opportunities. However, proper documentation of the performance of the plastic paving blocks and their cost is required to foster adoption of this revolutionary product within the pavement construction sector in Kenya. It is against this background this study was conducted to assess the suitability of plastic paving blocks for construction of Non-Motorised Transport facilities (Walkways and Cycle lanes). This would intensify the efficient use of plastic waste materials in the transport sector and promote safe walking and cycling by increasing the Non-Motorised Transport network within our urban centers.

1.2 PROBLEM STATEMENT

The influx of plastic use in our society makes plastic waste one of the biggest environmental concerns. As the population grows so does the amount of refuse, and this is amplified by the increased use of disposable plastic. The damage to the environment by plastic is long lasting due to its non-biodegradability causing land, air and water pollution. Plastic only starts degrading in 700 years. This means that all the plastic that has ever been produced has not degraded yet (World Counts).

Walking and cycling are described as 'forgotten modes' because despite acknowledgement of their importance they still got limited funding (FHWA, 1999). Walking is the oldest and most common mode of transport making up a portion if not most or all of our daily commute pattern; however, there's still inadequate infrastructure within our cities and towns to cater for the demand and volumes experienced. With focus mostly on the motorised transport, maintenance of the little infrastructure developed for pedestrians and cyclist is neglected as well.

This study set out to assess the suitability of plastic paving blocks for construction of Non-Motorised Transport (NMT) facilities. The samples made from mixing plastic waste and sand were tested to establish their physical and mechanical properties in accordance with South African National Standards (SANS) 1058:2021; the data recorded, analysed and interpreted. A purchase cost analysis was also undertaken comparing the price of one square meter of plastic paving block to that of conventional materials the concrete paving blocks.

The interpretation from the data would be used to justify any engineering decisions to be made with regards to adaptation of plastic paving blocks in construction of walkways and cycle lanes. The plastic paving blocks provide an alternate material for construction of NMT facilities that is affordable, readily available and environmentally friendly resulting to increase in walkways and cycle lanes in our urban centers while recycling plastic waste.

1.3 RESEARCH OBJECTIVES

The overall objective of this study was to assess the suitability of plastic paving blocks for use in the construction of Non-Motorised Transport facilities in Kenya.

1.3.1 Specific Objectives

To attain the overall objective, the study pursued the following specific objectives: -

i. To investigate the physical and mechanical properties of the plastic paving blocks.
ii. To investigate the purchase cost difference of concrete and plastic paving blocks.

1.4 RESEARCH QUESTIONS

The following research questions guided the study: -

i. What are the physical and mechanical properties of the plastic paving blocks?
ii. What is the purchase cost of concrete and plastic paving blocks?

1.5 SCOPE AND LIMITATIONS OF THE STUDY

The research was limited to investigating the physical and mechanical properties of plastic paving blocks by conducting water absorption, tensile strength and abrasion test guided by SANS 1058:2021 to assess the blocks suitability for use in the construction of NMT facilities. The slip resistance test was not performed because of budgetary constraints despite slip coefficient of Non-Motorised Transport facilities, walkways and cycle lanes being of paramount importance. This research also performed a purchase cost comparison to determine the difference in price of one square meter of concrete paving blocks to that of plastic blocks. However, a breakdown of cost of the various components used to manufacture the plastic and concrete paving blocks was not conducted due to limited information from the manufacturer and time constraints for conducting the study. Nevertheless, this study is relevant to the pavement construction industry as it provides the performance of plastic paving blocks as per SANS 1058:2021 and an engineering cost estimate comparison between the plastic and concrete paving blocks.

1.6 JUSTIFICATION FOR THE STUDY

The global demand for plastics continues to rise and the amount of plastics in circulation by 2030 is projected to increase from 236 to 417 million ton per year. Only 16 per cent of plastic waste is recycled to make new plastics, while 40 per cent is sent to landfills and 25 per cent to incineration and 19 per cent is dumped (Zoé and Michael, 2020). The use of plastic waste as a component in the paving block would facilitate environmental sustainability through recycling and reuse of plastic materials. This would significantly reduce the amount of plastic waste disposed improperly and also create employment opportunities in the informal sector through the collection, sorting and cleaning of plastic waste, as well as the manufacture and sell of the paving blocks.

The National Transport and Safety Authority (NTSA) reported that 65 per cent of road fatalities in the year 2017 involved pedestrians, 3 per cent involved cyclists making the total number of fatalities involving non-motorised transport users 68 per cent as represented in Figure 1-2. These numbers have continued to rise with the authority also reporting that 1,033 pedestrians died in 2019 compared to the previous year when 882 pedestrians lost their lives representing a 17 per cent increase over the one-year period.

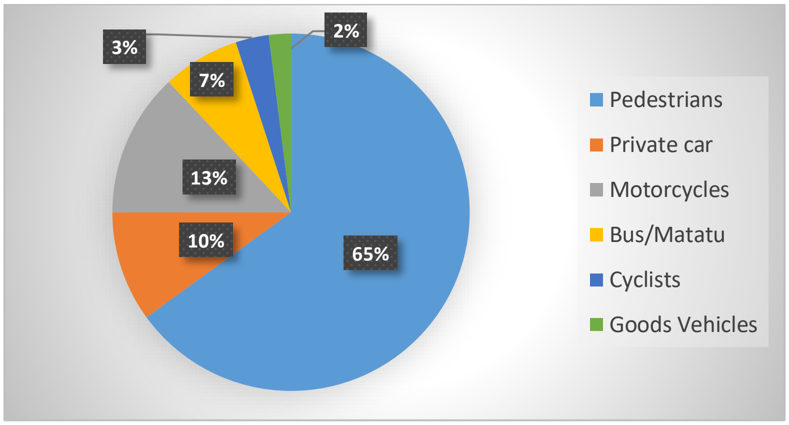


Figure 1-2: Representation of Fatal Road Accidents 2017
(Source: NTSA, 2017)

The use of plastic paving blocks for construction of NMT facilities would lead to an increase in NMT infrastructure (walkways and cycle lanes) consequently reducing number of accidents that involve pedestrians and cyclists, increasing mobility and accessibility while ensuring economic and transport sustainability. The net result would be a reduction in most of the transportation problems currently faced in the sector; congestion, accident rate, air and noise pollution. The increased use in human propelled modes would also promote mental and physical fitness improving health within the society.

CHAPTER 2 LITERATURE REVIEW

2.1 INTRODUCTION

In today's lifestyle plastic is everywhere and its disposal is a great challenge posing environmental pollution and health problems like breast cancer, genital abnormalities and reproductive problems in both humans and animals because it is a non-biodegradable material. A complete a ban on the use of plastics on emotional grounds is not feasible because the real cost would be much higher, the inconvenience much more and the chances of damage or contamination much greater. Hence judicious use and re-use of plastic-waste is the question and not "plastics vs no plastics" (Menaria, 2015).

Developing nations are experiencing a steady increase in traffic volumes more specifically in terms of commercial and heavy goods vehicles affecting the durability of roads constructed. Any damage on the roads causes a lot of inconvenience to the transportation systems ultimately affecting the future growth of these countries hence improved road characteristics are demanded. On the other side there is significant variation in daily and seasonal temperatures as a result of increased global warming and climate change. The combined solution for the above problems can be green roads constructed from plastic waste; providing economical and sustainable solutions to disposal of plastic waste with a commitment towards development of infrastructure and contributing for the betterment of society. Using plastic waste material in transportation projects implies eco-friendly construction of roads with alternative materials over the conventional materials (Pranav, 2018).

Urban mobility today is tending towards sustainable transport; purposing to improve accessibility by designing urban areas for people and not cars and encouraging use of greener modes of transport to reduce air and noise pollution. The concept purposes to provide equity to Non-Motorised Transport and public transport users by giving them the highest priority through an integrated transport and land use planning approach while promoting public participation and transparency during the planning and implementation of the projects.

2.2 PLASTICS

Plastics are polymers that generally contain carbon and hydrogen with sometimes other elements such as oxygen, chlorine, fluorine, or nitrogen. Plastic is a very large molecule made up of smaller units called monomers which are joined together in a chain by a process called polymerization

(UNEP, 2009). Plastics can be made hard as stone, strong as steel, transparent as glass, light as wood, and elastic as rubber because the molecules that compose plastics are long carbon chains that give plastics many of their useful properties. Plastics are also lightweight, waterproof, chemical resistant, and produced in almost any colour. More than 50 families of plastics have been produced, and new types are currently under development (Ahmed, 2003).

There exist natural plastics such as shellac, tortoiseshell, horns and many resinous tree saps according to the United Nation Environment Program guidelines Converting Waste Plastic into a Resource (2009), but the term "plastic" is commonly used to refer to synthetically (synthetic or semi-synthetic) created materials that we constantly use in our daily lives: in our clothing, aircraft, electronics, housing, automobiles, packaging, signs, medical implants and recreation items to name but a few of their many applications. These plastics are not just polymers which can be moulded or extruded into desired shapes but often contain additives that improve their performance. Plastics can be designed with a broad variation in properties according to the polymer used to be synthetic or semi-synthetic and can be modified by the addition of such additives.

Plastics are categorised by the different ways they respond to heat into thermoplastics and thermosetting plastics. Thermoplastics are defined as plastic polymers that can be moulded into desired shapes under heat and pressure and become hard upon cooling. They can be subjected to heating and cooling several times without altering their chemical and mechanical properties (IRC: SP:98-2013). Weak Van der Waal forces hold together the molecules in thermoplastics and do not chemically bond with each other when heated. They are linear or slightly branched forming long molecular chains that clump together like piles of entangled spaghetti. This characteristic consequently allows thermoplastics to be remoulded and reused almost indefinitely (Ahmed, 2003).

Thermosetting plastics on the other hand contain polymers that cross-link and form irreversible chemical bond during the curing process. Once formed they cannot be softened or remoulded by heat application (IRC: SP:98-2013). Thermosets create permanent three dimensional network that consists of chain molecules that cross link and chemically bond with each other when heated. In the same way cured concrete cannot be reset; thermosets cannot be re-melted once cured. Thermosets are often used to make heat resistant products because they can withstand temperatures of up to 260^0 c without melting (Ahmed, 2003).

2.2.1 Types of Plastic

There is a vast variety of plastics and they are classified on the basis of the polymer from which they are made (UNEP, 2009) as shown in Table 2-1 and are further discussed in section 2.2.1.1 and 2.2.1.2.

Table 2-1:Types of Plastics (Thermoplastics and Thermosets)

THERMOPLASTIC	THERMOSETTING
Polystyrene (PS)	Alkyd
Polypropylene (PP)	Melamine
Poly Vinyl Chloride (PVC)	Bakelite
Polyethylene Teryphthalate (PET)	Urea – Formaldehyde
Poly Vinyl Acetate (PVA)	Epoxy
High Density Polyethylene (HDPE)	Polyester
Low Density Polyethylene (LDPE)	

(Source: IRC:SP:98-2013)

2.2.1.1 Thermoplastics

The most commonly manufactured thermoplastics are discussed in this section.

Polyethylene

Polyethylene are derived from ethylene (CH2=CH2). The resins are translucent, milky white, substances. Polyethylene, with the chemical formula [-CH2-CH2-]n is made in low- and high-density forms. The plastic molecule is formed by the chemical formula inside the brackets repeating itself (Ahmed, 2003). Therefore, there are two main types of polyethylene namely high density polyethylene (HDPE) and low-density polyethylene (LDPE).

Low-Density Polyethylene (LDPE) has a density ranging from 0.91 to 0.93 g/cm^3. They have a carbon backbone with randomly attached side groups of four to six carbon atoms along the backbone. It is flexible, inexpensive, chemical resistant, and extremely tough making it the most widely used of all plastics (Ahmed, 2003). It is used in the manufacture of a wide array of items such as film bags, food boxes, toys, flexible piping and hosepipe, sacks and sheeting, blow-moulded bottles, telephone cable sheaths, household articles such as buckets and bowls, etc (UNEP, 2009).

High-density polyethylene (HDPE) has a density ranging from 0.94 to 0.97 g/cm^3. Its molecules have an extremely long carbon backbone without side groups aligning into more compact arrangements, accounting for its higher density. Compared to ow-density polyethylene it is stiffer, stronger, and less translucent (Ahmed, 2003). It is used to manufacture jerry cans, detergents and cosmetics containers, bags and industrial wrappings, crates, soft drinks bottles, toys, dustbins and other household articles (UNEP, 2009).

Polyethylene Terephthalate (PET)

Polyethylene terephthalate is a monomer [-OOC-C6H4-COO-CH2CH2-]n produced from the reaction of ethylene glycol (HOCH2-CH2OH) and terephthalic acid (HOOC-C6H4-COOH). Its molecules create a strong and abrasion resistant material that is used to produce films and polyester fibers (Ahmed, 2003). Polyethylene terephthalate is a semi-crystalline (opaque and white) thermoplastic material that exists as an amorphous (transparent) with good resistance to mineral oils, solvents and acids but not to bases. The semi-crystalline Polyethylene terephthalate has good strength, ductility, stiffness and hardness while the amorphous type has better ductility but less stiffness and hardness. Polyethylene terephthalate has good barrier properties against oxygen (O_2) and carbon (IV) oxide (CO_2). Hence, it is utilized in bottles for mineral water, food trays for oven use, roasting bags, audio/video tapes as well as mechanical components and synthetic fibers (UNEP,2009).

Polypropylene (PP)

Polypropylene is polymerized from the organic compound propylene (CH3-CH=CH2). Along the molecular backbone it has a methyl group (-CH3) branching off of every other carbon. The most common form of polypropylene has the methyl groups all on one side of the carbon backbone. Polypropylene are durable and chemical resistant because its molecules tend to be highly aligned and compact. It is used in the manufacture of rope, carpet, luggage, fiber, and packaging film (Ahmed, 2003).

Polystyrene (PS)

Polystyrene has six-member carbon ring (phenyl groups) attached in random locations along the carbon backbone of the molecule and is produced from styrene (C6H5CH=CH2). The molecules are prevented from becoming highly aligned because of the random attachment of benzene making polystyrene a transparent, amorphous, and somewhat brittle plastic. Polystyrene is widely used because of its rigidity and superior insulation properties. Polystyrene can undergo all thermoplastic processes to form products such as display boxes, toys, model aircraft kits, utensils, and ballpoint pen barrels. It is also expanded into foam plastics for packaging materials, flotation devices, egg cartons, and Styrofoam (Ahmed, 2003).

Polyvinyl Chloride (PVC)

Polyvinyl chloride is the most widely used of the amorphous plastics and is prepared from the organic compound vinyl chloride (CH2=CHCl). It is durable, lightweight, and waterproof. As a result of the chlorine atoms bonding to the carbon backbone of its molecules the polyvinyl chloride acquires hard and flame-resistant properties. Polyvinyl chloride is extruded into gutters, pipe and house siding because in its rigid form, PVC is weather-resistant. Rigid PVC is also blow moulded into clear bottles and is used to form other consumer products, including compact discs and computer casings. Polyvinyl chloride can be softened with certain chemicals and this softened form is used to make shampoo containers, shrink-wrap, rainwear, food packaging, shoe soles, upholstery, floor tile, gloves, and other products (Ahmed, 2003).

2.2.1.2 Thermosetting plastics

Thermosetting plastics from irreversible links when heated and are used to manufacture durable and heat-resistant materials.

Polyurethane

Polyurethane is a polymer consisting alkyl groups chemical groups obtained by removing a hydrogen atom from a hydrocarbon containing all carbon-carbon single bonds (alkane) with repeating unit [-R-OOCNH-R’-]n, where R may represent a different *alkyl group* than R’. To form thermosetting plastics, most types of polyurethane resin crosslink into a single giant molecule. However, some polyurethane result in thermoplastics because their resins have a linear molecular arrangement that does not cross-link. They are moulded into car fenders, shoe soles, door panels, and other products (Ahmed,2003).

Urea-Formaldehyde and Melamine-Formaldehyde

Melamine-formaldehyde (MF) and Urea-formaldehyde (UF) resins are composed of molecules that cross-link into hard, clear plastics. These resins are formed by condensation reactions between formaldehyde (CH_2O) and melamine ($C_3H_6N_6$) or urea (H_2NCONH_2). House and kitchen appliances such as knife handles, plates and door knobs are formed from urea-formaldehyde resins. They are also used to bond wood sheets and chips into plywood and chip board and give wash and wear clothes drip-dry properties. Melamine-formaldehyde (MF) compared to urea-formaldehyde plastics are more scratch proof, heat and stain resistant and are used in the manufacture of laminated furniture veneers, dishware, bond wood layers into plywood, and electrical components. MF resins are also easily moulded in special injection and compression machines. (Ahmed, 2003).

Epoxy

Epoxy (EP) resins are named for the epoxide groups that terminate the molecules with a chemical formula cycl-CH2OCH; the triangle formed by this group is referred to as *cycl* or *cyclic*. Epoxies are extremely weather-resistant, tough, and do not shrink as they cure (dry); these useful properties are given by the oxygen along epoxy's carbon and the epoxide groups at the ends of the carbon chain. Epoxies cross-link and form three-dimensional molecular network when a catalyzing agent (hardener) is added to them. Epoxies are instrumental in the aerospace industry as they are used to make all composite aircrafts, horizontal stabilizers for F-16 fighters, wing skins for F-22 and F-18 fighters and B-1 bomber. They are also used to make composite laminates, coatings and adhesives because of their outstanding bonding strength (Ahmed,2003).

Unsaturated Polyesters

Unsaturated polyesters (UP) belong to the polyester group of plastics. Polyesters are composed of long carbon chains containing [-OOC-C6H4-COO-CH2-CH2]n. Unsaturated polyesters contain multiple bonds that copolymerize when long molecules are joined and crosslink by the aromatic organic compound styrene. Unsaturated polyester resins are often premixed with glass fibers for additional strength. Sheet Moulding Compounds (SMC) and Bulk Moulding Compounds (BMC) are types of premixed resins with dough-like consistency and may contain short fiber reinforcements and other additives. Sheet moulding compounds are preformed into large sheets or rolls that can be moulded into products such as small boat hulls, shower floors, and roofing materials. Bulk Moulding Compounds are also preformed to be compression moulded into car body panels and other automobile components (Ahmed, 2003).

2.2.2 Plastic/Resin Identification Code

The resin identification code was developed in 1988 by the Society of the Plastics Industries (SPI) to provide manufacturers with a consistent and uniform system to facilitate the recycling of postconsumer plastics by identifying the resin content of plastic bottles and containers. The SPI coding, by which a number is recorded within the plastic item to specify the type of polymer used in its manufacture process, focused on the plastic packaging commonly found in the residential waste stream. Polyethylene terephthalate (PET or PETE), low density polyethylene (LDPE) high density polyethylene (HDPE), polyvinyl chloride (PVC or vinyl), polypropylene (PP), and polystyrene (PS) are the six types of polymers that constitute the majority of plastic packaging. Therefore, SPI resin identification code assigned each of the mentioned resins a number from 1 to 6 as shown in Plate 2 -1. For products made with resin other than the six listed above, a seventh code is included identified as "other" (UNEP,2009).

Plate 2-1: Plastic Identification Code
(Source: UNEP,2009)

2.3 PLASTIC PAVEMENTS

Disposal of plastic waste is a major challenge and improper disposal has adverse effect on the environment. Plastic does not decay over time and always finds its way back to the environment even when disposed in landfills through air and water. The conundrum brought about by disposal of plastic waste can only be solved once ground level measures are put in place to ensure recycling is done to the maximum extent.

The use of plastic in pavement construction is one way to recycle and reuse the plastic waste generated. This use of alternate materials for pavement construction would be timely because there's been an increase in use of non-biodegradable materials in the construction industry because of limited natural resources, increase in infrastructure demand due to increased population, and global warming and climate change is also on the rise (Pranav, 2018).

2.3.1 Process in the Manufacture of Plastic Paving Blocks

The paver block is functional, versatile, cost effective, aesthetically attractive, and requires little or no maintenance if correctly manufactured and laid. Most concrete paving blocks manufactured have performed satisfactorily however, variability in the strength of the block and excessive surface wear have resulted to occasional failure. With depleting natural resources worldwide and increasing wastes generated from the industry and residential area; the replacement of cement for plastic in the manufacturer of paving blocks provides innovative and non-conventional alternative materials for construction. Compensating for the lack of natural resources and also conserving the environment providing potential environmental as well as economic benefits. (Shanmugavalli et al, 2017).

The three main components used in the manufacture of the plastic paving blocks are plastic waste, river sand and red oxide. Accumulation of plastic waste can result into hazardous effects to both human and plant life; therefore, need for plastic management through proper disposal and recycling of the plastic waste (Dinesh et al, 2016).

There are various waste generating sectors namely Residential, Commercial, Industrial, Construction and Demolition, Electrical and Electronic Equipment waste. Waste generated from households such as single-family or multi-family houses and buildings are categorised as residential waste. Waste generated from commercial entities such as shopping malls, markets or offices is commercial waste. Industrial waste is waste generated by industries and may be hazardous or non-hazardous. E-Waste also known as Waste Electrical and Electronic Equipment (WEEE) is one of the fastest growing waste streams in the world. Its composition is varying and diversifing in products across different categories. Construction and Demolition (C&D) waste is also another waste generating sector that may not contain substantial portion of waste plastics. Segregation of the plastics from other streams of waste is highly recommended and additionally, polyvinyl chloride should also be segregated as a separate stream from other plastics. The plastic waste generated constitutes 80 per cent thermoplastic and 20 per cent thermosets (UNEP, 2009).

The unique characteristic of thermoplastics allowing them to maintain their chemical properties even after subjecting them to repeated heating and cooling makes them highly recyclable. The guidelines for use of plastic waste in hot bituminous mix by Indian Roads Congress (2013) stipulates that only plastics that fall in the thermoplastic category and conform to Polyurethane (PUR), Polyethylene Teryphthalate (PET), Low Density Polyethylene (LDPE) and High Density Polyethylene (HDPE) shall be used for pavement construction. Poly Vinyl Chloride (PVC) shall not be used because they release harmful and lethal dioxins when heated. The different types of thermoplastics each have unique characteristics as described in Table 2-2 that also provides examples of their sources. Plastics black in colour shall not be used because they contain highly poisonous additives such as lead and mercury and flame retardants. During recycling the black plastic would mix with the other plastics further rising the toxin levels beyond legal limits. At 180°C and beyond thermal degradation and gas evolution may occur as revealed by the Thermo Gravimetric Analysis (TGA) of thermoplastics. Thus misuse or wrong implementation of waste plastic recycling may result in premature degradation and release of harmful gases, if the temperatures are not maintained within safe limits during manufacturing (IRC:SP:98-2013).

Table 2-2: Types of Thermoplastics, characteristics and origin

Waste Plastic	**Characteristic**	**Origin**
Polystyrene	Made from Monomer Styren Synthetic aromatic hydrocarbon polymer Can be solid or foam.	Plastic cutlery, egg boxes, disposable cups, foam packaging
Polypropylene	Produced from monomer propylene by chain growth polymerization	Straws, packaging tape, bottle caps, detergent wrappers
PolyVinyl Chloride	Made from Vinyl Chloride.	Credit cards, toys, furniture, folders, medical disposables such as blood bags, gloves, pens
Polyethylene Teryphthalate	Most common thermoplastic Consists of polymerized ethylene terephthalate monomer units	Food trays, drinking water bottles, cosmetic containers
High Density Polyethylene	Produced from monomer ethylene	Corrosion resistant piping, detergent bottles, shampoo bottles, milk bottles
Low Density Polyethylene	First grade of polyethylene produced by using high pressure process.	Plastic wraps, playground slides, trays, general purpose containers. Packaging for computer hardware such as hard drives

(Source: IRC: SP:98-2013)

River sand is naturally occurring granular material which is composed of finely divided material and mineral particles. The composition of sand varies depending on the local rock conditions and sources. Silica (IV) oxide (SiO_2) is the most common sand in inland continental settings and non-tropical coastal region and is in the form of quartz. Sand is now used in all the construction process (Dinesh, 2016). Red Oxide also known as Iron (III) oxide or ferric oxide is the inorganic compound with the formula Fe_2O_3. It is ferromagnetic, dark red, and readily attacked by acids. The properties of red oxide is to make colouring to the paver blocks (Dinesh, 2016).

In the first step waste plastic is collected from roads, dumping sites such as Dandora, Mathare, Kariobangi, and garbage trucks. In Kenya, the companies work with various groups in the city such as Power line Undugu Youth Group, Evans Karuga and Associates, John Ndung'u and Associates, Wendo Women Group and Kariobangi Waste Management Alliance by setting up collection points in Dandora, Mathare, Kariobangi and the University of Nairobi – Chiromo campus and purchase a kilogram of plastic waste at 30¢. The collected waste is then sorted, dusted and washed and left out to dry. After cleaning and drying, the waste is cut into small manageable sizes by a shredding machine. The sand is mixed with colour of choice like Red, Gray or Green. The shredded plastic is then mixed with the coloured sand at a temperature between 140^0 – 170^0 c. The Continental Renewable Energy Co. Ltd has adopted a mix design ratio of 30 per cent plastic waste and 70 per cent river sand for their plastic paving blocks. The temperature should not exceed 180^0 c to avoid gas evolution. The mix is weighed and a desired 1.8 kilograms obtained for the rhombus block. The weighed mix is placed in mould, cooled with water and air dried for at least 2 hours (Dinesh, 2016). The described steps are represented in Figure 2-1.

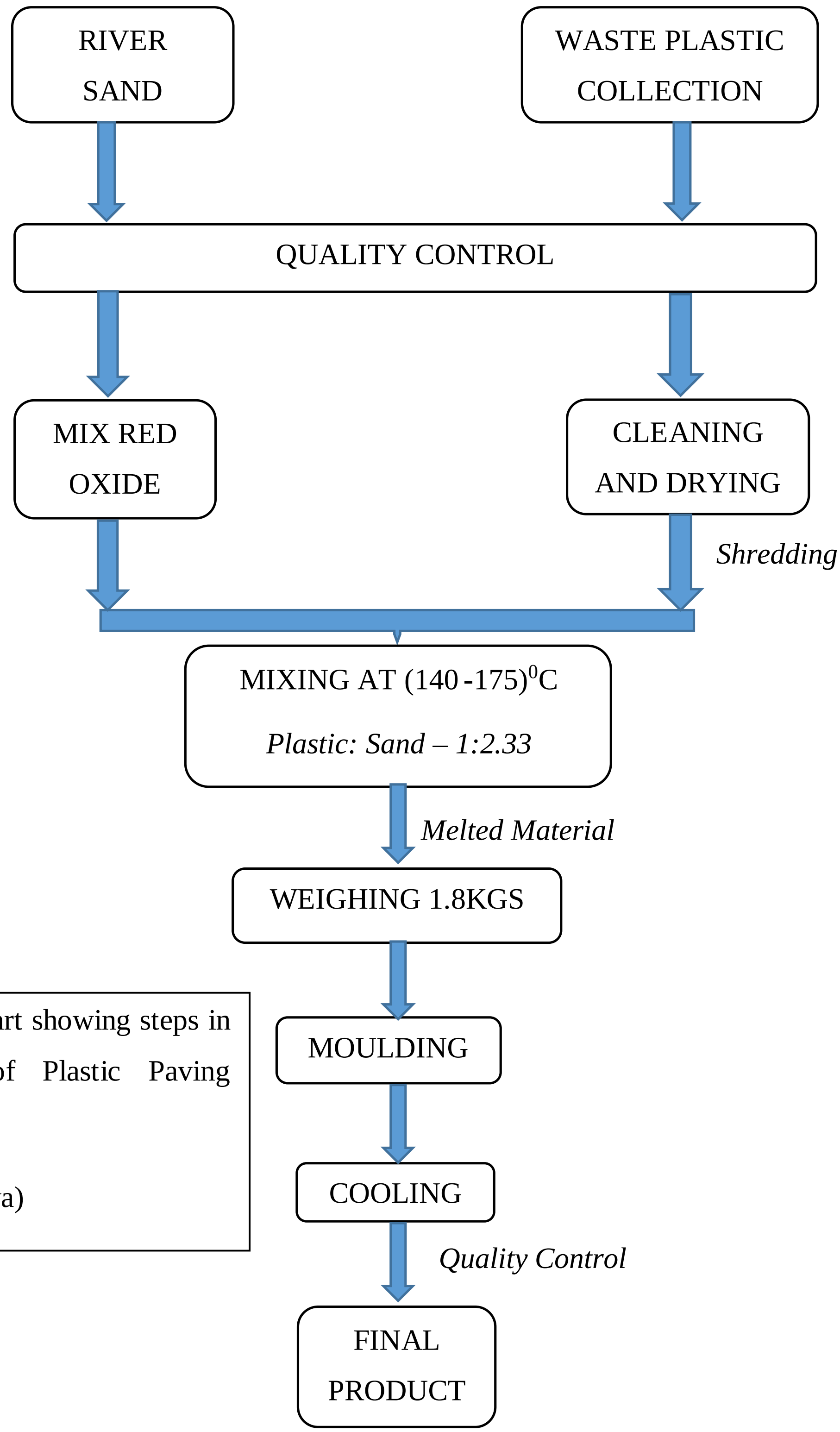


Figure 2-1: Flow chart showing steps in the manufacture of Plastic Paving Blocks

(Source: Corec Kenya)

2.3.2 Installation of the Plastic Blocks

The area to place the paving blocks is identified and mapped out using sticks or wood. The number of paving blocks needed is calculated by determining the area of the identified space. The figure obtained is always increased by 5 per cent to allow for the paving blocks that will be cut to fill the curves and odd spaces. About 100mm are excavated for the base, 25mm for the sand bed and 50mm for the thickness of the block. It is always ensured that there's a gradient or slope to avoid ponding. The surface is compacted to provide a firm surface. The base material that consists of crushed stone is laid, spread over the area and compacted. The edge restraints are installed to ensure the blocks do not move and separate. A layer of sand is placed over the compacted base material to provide a bed to lay the paving blocks. This protects the sand joints from erosion. The paving blocks are then laid in the desired design and pattern. Sand is swept over the surface to fill up the joints and lock the blocks into place. The expected end result is shown in Plate 2-2 that captures ongoing installation of the plastic paving blocks by Corec – Kenya.

Plate 2-2: Installed Plastic Paving Blocks
(Source: Corec Kenya)

2.4 EVOLUTION OF TRANSPORT

Transportation is fundamental for a country's growth and development as it greatly impacts the ease of conducting economic and social activities in a region. It is indispensable and continues to play a major role in facilitating trade, commerce and social interactions. Valuable links are formed between people, communities, regions and the rest of the world through transport. The increase in demand, reduction in cost and continued expansion of transport systems and infrastructure indicates the importance of transport is growing and will continue to (Rodrigue, 2020).

Evolution within the transport sector led to the invention of automobile in the 1800s by Germany and France. The automobile age was experienced in the 20th century because in 1940 Ford innovated mass-production techniques that became standard; making the invention accessible to a lot of people in the United States of America. This drastically reduced the cost of the automobile to a quarter of the cost in the previous decade (Rae *et al*, 2020). The rise of Japanese Automakers made it possible for the rest of the world to have access to the invention by manufacturing affordable, functionally designed, well-built small cars leading to a rise in vehicle ownership. In Kenya, the number of motor cars rose steadily from 1998 to 2011 as exhibited in the graphical representation in Figure 2-2 (KNBS, 2012). The automobile changed the way people moved from one place to another making mobility more efficient. Other positive impacts are job creation through blossoming of other industries such as oil, steel and vulcanised rubber manufacturing not to mention construction of highways. Increased motorisation however, has also led to the upsurge of the various urban challenges.

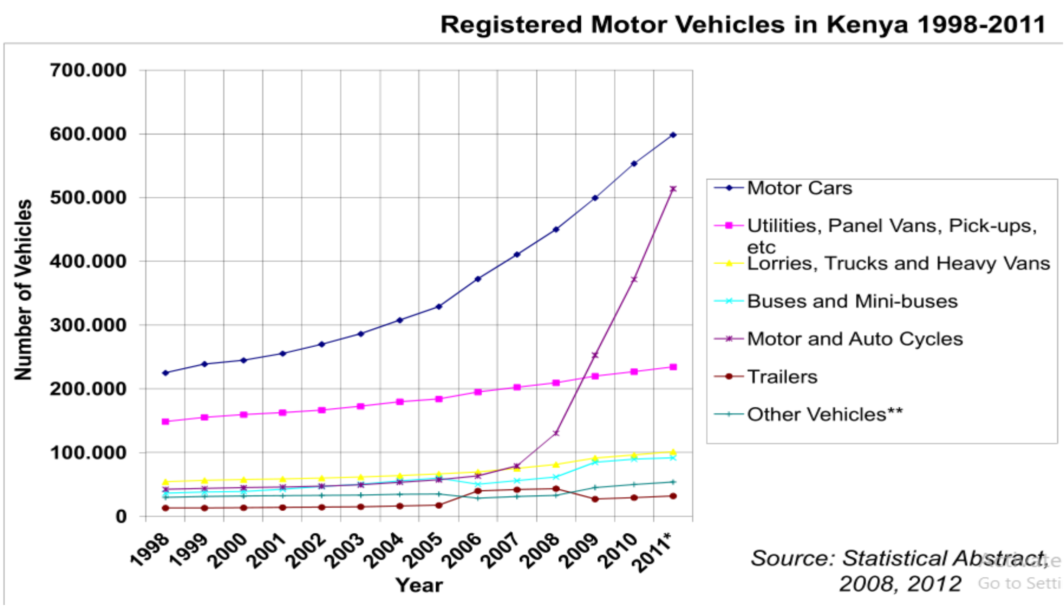


Figure 2-2: Representation of Vehicle Ownership in Kenya 1998 – 2011

(Source: KNBS, 2012)

The increased number of vehicles on the road led to congestion. Despite continued investment in development of transportation infrastructure to increase carriageway capacity, congestion in towns and cities has increased due to the increase in automobile ownership. This leads to a negative impact on personal productivity and region's economy due to the increased hours spent in traffic for daily commute. In addition, motorisation encouraged people to move further out to the suburbs where amenities were cheaper leading to urban sprawl. People now live in uncontrolled development areas far away from their work places leading to an increase in the amount of time spent on the road (Rodrigue et al 2006). The number of accidents occurring on the roads have also increased with increase in the number of vehicles on the road and development of infrastructure that is more suited for vehicles making fatalities from pedestrians the highest in any urban area. Road traffic injuries are currently estimated to be the 8th leading cause of death across all age groups globally causing 1.35 million deaths annually. 54 per cent of those dying on the world's roads are vulnerable road users that comprise of pedestrians, cyclists and motorcyclists (WHO, 2022). On the environment, motorisation has led to an increase in air and noise pollution with Internal Combustion Engine (ICE) vehicles being responsible for 34 per cent of nitrogen dioxide emissions into the environment. They are also responsible for 51 per cent of carbon (II) oxide, 10 per cent of particulate, and 33 per cent of carbon (IV) oxide emissions (Climate Change action, 2016) adversely affecting the ozone layer leading to global warming and climate change. The mechanism used to produce the kinetic energy needed for movement of the vehicle produces noise leading to noise pollution.

These challenges from increased motorisation can be reduced by embracing sustainable transport that promotes the use of environmentally friendly modes like walking and cycling. The Institute for Transportation and Development Policy (ITDP) recommends a paradigm shift prioritizing the majority in the modal split as shown in Plate 2-3 for the design of our transportation systems and emphasise on developing a system that promotes non-motorised transport, improves the public transport system by providing an efficient, integrated and safe service and lastly proper traffic management initiatives (SMDUAK, 2019).

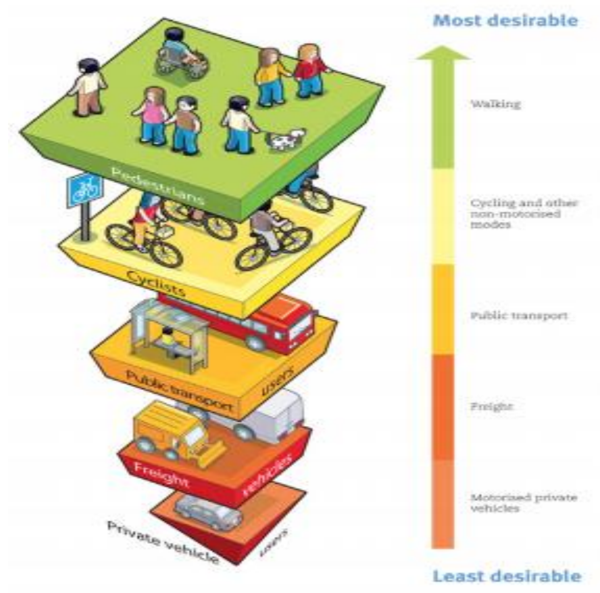


Plate 2-3: Reverse Pyramid for Design of Transportation Systems
(Source: SMDUAK, 2019)

2.5 SUSTAINABLE TRANSPORT

The traditional urban transport planning emphasised on a car-centred approach where large blocks of land with uniform use were established. Suburbs were a common phenomenon, central business districts were predominantly commercial and roads were built for high speeds and limited accessibility. This approach facilitated rapid growth of urban areas and rise in motorisation leading to increase in urban transport problems such as traffic congestion (Ковачев et al, 2018).

The challenges faced in urban transportation, are exacerbated by the relative decline of public transport usage as a result of shift from public to private sector provision of public transport services and facilities making the industry poorly regulated and profit driven as the services are not demand driven hence making the use of private vehicles more reliable. The long distances between the work and residential areas that currently exist further encourage many commuters to use private vehicles for their daily commute to and from work. Other problems as a result of increased motorisation are increased accidents, air and noise pollution. However, current trends and patterns such as home entertainment and telecommuting enabled by technological advancements is making the use of private vehicles unpopular consequently forcing urban and transport planners to rethink the structure of our urban areas (O'Flaherty, 2006).

Sustainable transport seeks to support the society's mobility needs in a manner that is least damageable to the environment and does not impair the mobility needs of future generations (Rodrigue, 2006). It concerns provision of modes, infrastructure and operations facilitated by systems, policies and technologies to significantly reduce negative effect of transport on the environment, economy and society. For the environment, sustainable transport aims to reduce the environmental impacts of transportation through prevention of noise and air pollution by encouraging the use of green transport and energy such as walking, cycling, electricity, solar energy, and compressed natural gas (CNG). To achieve sustainable transport, the following approaches Land use planning, public transport planning and demand management (O'Flaherty, 2006) are recommended and discussed in detail through section 2.5.1 to 2.5.3.

2.5.1 The Land Use Planning Approach

The relationship between transport and land use is complex but cannot be overlooked. Transport plans that put consideration to land use and its impacts acknowledges that control of land use is key to control travel demand and environmental impact from transport systems. Increased personal mobility brought about by the private car has led outward spread and decentralisation of people and jobs to suburbia and smaller towns in non-metropolitan areas resulting to increased physical separation homes jobs and other facilities. By integrating transport and land use, residential settlement patterns will be influenced resulting to increased accessibility to commercial areas without the need to travel by a car (O'Flaherty, 2006).

This is done by establishing land use control measures through Transit Oriented Development (TOD) that promote mixed land use within urban centres. Having both residential and commercial land uses in close proximity of each other, limits the spread of cities so as to keep up residential densities and increase the supply of housing in the existing larger urban areas where they can be easily accessible to existing facilities. These are supported by traffic management measures such as implementing priority measures that promote use of public transport, safe walking and cycling, establishing car free zones in urban centres, limiting amount of car commuting to new developments that are well served by public transport and shifting significant proportion of the supply of parking from the central and inner city to an interchange location with park and ride facilities.

2.5.2 The Public Transport Planning Approach

This approach focuses on measures that improve and encourage the use of public transport. The use of public transport helps retain employment and other economic activities in a central area, is more efficient, minimises impact on the environment through reduced emissions and amount of land used for transport. It is important to note that a shift to use of public transport can only be realised if the service provided is efficient, affordable, integrates with other modes, provides seamless transfers at nodes, and uses clean and comfortable vehicles (O'Flaherty, 2006).

2.5.3 The Demand Management Approach

This entails more effective management of demand on the existing transportation system by reducing the pressure on them rather than constructing new links. Strategies include encouraging use of public transport, promoting 24-hour economy to facilitate staggered working hours, promoting telecommuting, road pricing, and establishing stringent parking control measures (O'Flaherty, 2006).

However, it is important to note that urban transport plans do not rely wholly on any of the contrasting approaches described above but proposals are developed incorporating each one of them depending on the distinct characteristics of the urban centre providing an ideal environment that promotes use of public and non-motorised transport.

2.6 NON-MOTORISED TRANSPORT

2.6.1 Background

Walking and cycling are the two modes of transport categorised as Non-Motorised Transport (NMT). They are considered active modes of transportation because they are human powered. The Integrated National Transport Policy of Kenya (2009) also categorises wheelchair travel, hand carts, scooters, skates, skate boards and modified bicycles as NMT. In urban areas, NMT takes up the largest share of trips because its affordable and flexible. It is ideal for short haul trips of up to 5 kilometres and can be used for recreational and transportation purposes (INTP, 2009).

In the provision of NMT infrastructure it should be ensured that safety is provided through installation of proper lighting along the route, walkways should be built on the desire lines with the shortest path possible giving the pedestrian a direct route for movement, the pavement is properly installed and maintained to give the pedestrian comfort as they walk. The network should be coherent and integrated with other modes of transport providing continuity as highlighted in the Florida Pedestrian Planning and Design Handbook (1999). The guidebook further stipulates that all roadways where pedestrians are expected should have a walking area that is out of the vehicle travel lanes, developers should be required to incorporate sidewalks into every residential, commercial, and industrial projects, schools should provide sidewalks into their site and direct connections between residential and activity areas such as shopping centers and transit stops should be provided. Non-motorized transport plays an important role in mobility management. When vehicle is reduced, many trips shift to walking and cycling, either entirely or in conjunction with ridesharing and public transit use (Todd, 2009).

2.6.2 Benefits on NMT

The National Bicycling and Walking Study Report (2010) by US Transportation Department Federal Highway Administration highlights the transportation, health, environmental, and economic benefits associated with walking and cycling. Pedestrians and cyclists are more efficient users of limited road space compared to private vehicles. This helps in reducing traffic congestion the most visible and major challenge in the transportation sector. Most of our urban areas were established focusing on the car-centered planning approach encouraging people to use private vehicles for short haul trips; investment in adequate and proper walkways and cycle paths can trigger a shift to NMT alleviating congestion altogether.

As active modes of transport NMT are physical activities and have great health benefits. When done regularly can produce immense benefits to the human body. They reduce the risk to lifestyle diseases such as diabetes, obesity, heart disease, depression and other chronic diseases. Health care costs are also significantly reduced with increased physical activities. Studies indicate that cycling for 30 minutes a day reduces chances of cardiovascular diseases by 50 per cent (FHWA, 2010). Transportation is responsible for about a fifth of global carbon (IV) oxide and carbon (II) oxide emissions according to our world in data website. The website further notes that in 2016, global carbon (IV) oxide emissions were 36.7 billion tonnes and 7.9 billion tonnes of the emissions were from transport accounting for 21 per cent of the emissions. Increased use of NMT reduces energy consumption in the transportation sector thus decreasing carbon emissions from the sector.

The use of NMT is cost effective significantly reducing the travelling cost. Savings are derived from reduced spending on the fuel, vehicular maintenance cost, public transport fares, licensing and registration fees. In addition, promoting NMT in cities that have undergone urban decay revitalizes businesses and brings new economic life to the centres. The various benefits of Non-Motorised Transport through reduced congestion, roadway and vehicle cost savings, noise and air pollution, energy conservation and traffic safety and their monetised estimates where possible are elaborated in Quantifying the Benefits of Non-Motorized Transportation for Achieving Mobility Management Objectives (Todd, 2009).

Traffic congestion external costs per average urban-peak vehicle kilometre is 10¢ to 20¢ and more in some situations. These costs are comprised of the vehicle operating costs, incremental travel time, pollution emissions and stress imposed on other road user by each vehicle (Todd, 2009). Under urban peak conditions, benefits from congestion reduction per reduced vehicle-kilometer are estimated to be worth an average of 20¢ per kilometer conditions and 10¢ per kilometer under urban off-peak conditions. In the rural areas a no congestion benefit is assumed. Roadway construction and maintenance costs average about 25¢ per kilometer for vehicles and are a function of vehicle size, weight, speed, and, in some regions, studded tire use. These costs are higher for heavier vehicles (FHWA, 1997). The complimentary traffic services required by motorized transportation such as signals, policing, and emergency response further increase the overall cost of road way construction and maintenance. Non-motorised transport imposes minimal roadway wear, and their traffic service costs tend to be lower than for motorised transport since pedestrians and cyclists impose less risk on others due to slower travel speed. Shifts from driving to walking or cycling are estimated to provide cost savings of 3¢ per kilometre for urban driving and 2¢ per kilometre for rural driving. (Todd, 2009). Direct vehicle operating costs such as parking fees, tolls, fuel tire and wear average about 6¢ per kilometer, plus another 6¢ per kilometre in mileage-based incremental insurance costs, repair, and depreciation. The cost of operating vehicles in short urban trips tends to be about 50 per cent higher due to cold starts (before the vehicle engine has warmed up), and congestion. Vehicle owners also incur fixed vehicle costs that they pay regardless of how much a vehicle is driven averaging about $5 per day (Todd, 2009). After about one year of normal use, a $50 pair of shoes typically lasts 1,600 kilometres of walking this translates to about 3¢ per kilometre-walked. Cyclists incur an average cost of 3¢ per kilometers cycled assuming a $750 bicycle ridden for 5,600 kilometers annually requires about $100 for annual maintenance and lasts 10 years.

In a typical household, transportation is the second largest category of expenditures after housing expense due to the high cost of owning motor vehicles. Significant savings can be realised with increased use of Non-Motorised Transport especially for lower income households. For example, improved walkways and cycle lanes conditions may enable a household to own one rather than two vehicles, or even give up vehicle ownership altogether, resulting to thousands of dollars in annual savings. Shifts from motorised to non-motorised travel provides savings that are estimated to average 15¢, 12¢ and 6¢ per kilometer under urban-peak conditions, urban off-peak conditions, and under rural conditions respectively (Todd, 2009). Other benefits such as air pollution, energy conservation, traffic safety benefits and parking cost are indicated in Table 2-3. While other benefits such as health and fitness, user enjoyment, community liveability, improved mobility for non-drivers, economic development, strategic land use objectives and any additional environmental benefits are not monetised thus the total value of shift from motorised to non-motorised transport is higher than the total estimates indicated in Table 2-3 (Todd, 2009).

Table 2-3: Monetary Representation of Estimated Benefits of NMT

ESTIMATED BENEFITS OF NON-MOTORISED TRANSPORT			
BENEFITS	**URBAN PEAK**	**URBAN OFF-PEAK**	**RURAL**
Congestion Reduction	$0.20	$0.10	$0.00
Roadway Cost Savings	$0.03	$0.03	$0.02
Vehicle Cost Savings	$0.25	$0.20	$0.15
Parking Cost (per trip)	$2.00	$1.00	$0.50
Air Pollution Reduction	$0.10	$0.05	$0.01
Noise Pollution Reduction	$0.03	$0.02	$0.01
Energy Conservation	$0.05	$0.04	$0.03
Traffic Safety Benefits	$0.05	$0.04	$0.03
Total per kilometer	>$1.70	>$0.90	>$0.5

2.7 NON-MOTORISED TRANSPORT IN KENYA

The Government of Kenya acknowledges the role of transport in economic growth and has invested greatly in the development of road infrastructure increasing their capacity and improving the condition. At a cost of 360 million USD the Thika Road (A2) that originates from Nairobi City and extends to Moyale, Ethiopia was one of the first major road infrastructure projects that upgraded the international trunk road from a dual carriage-way to an eight-lane highway with controlled access. However, congestion is still a problem that continues to plague commuters, residents and business owners along the corridor (KARA *et al*, 2012).

Road expansion has underlying effects that impact the traffic volume such as increased ownership of vehicles, increased economic activities along the corridor and a shift of settlements hence leading to congestion in the long run. Lewis Mumford in the Roaring Traffic Boom (1955) equates adding highway lanes to deal with traffic congestion to loosening one's belt to cure obesity. This has prompted the government to shift its approach and embrace sustainable transport initiatives so as to overcome the challenges faced on Kenyan urban roads.

2.7.1 The Integrated National Transport Policy Paper - INTP

Developed in 2009, the paper recognizes that despite the country's elaborate road network 60 per cent of residents within Nairobi meet their travel needs by walking. Over the years, attention has been mainly focused on providing infrastructure for motorised transport because NMTs are not fully recognized by law to qualify for the governments financial and technical support. The lack of development of NMT is a challenge faced within the transportation sector in Kenya hindering its performance of facilitative role in national, regional and international economics.

The paper recommends the integration of non-motorised and intermediate means of transport into Kenya's transport system with the objective of encouraging use of NMT to reduce the burden experienced in urban transport. The strategies highlighted in the paper to achieve this are provision of appropriate and adequate NMT infrastructure, establishment of standards and specifications for NMT, harmonization of NMT and accompanying infrastructure into legal, technical, and institutional mandates of transport and road authorities to ensure incorporation of NMT in urban and rural road network.

2.7.2 The Nairobi City County NMT Policy

The Policy paper developed in 2015 by Nairobi County aims to develop and maintain a transport system that provides seamless integration with NMT. This would be achieved by developing safe, cohesive and comfortable footpath and cyclelane network with green areas and other ammenities.

Laws and regulations shall be set in place by Nairobi County Government to protect the NMT zones from encroachment.

Implementation of the policy is seen within the Nairobi CBD with conversion of parking spaces to walkways. Funding of the project was through a 20 per cent allocation from the transport budget set aside for NMT and public transport infrastructure. The transformation on Kenyatta Avenue in Nairobi CBD is captured in Plate 2-4 and 2-5 below after the conversion of parking spaces on the service lane to walkways and cycle lanes creating a friendlier environment for pedestrians and cyclists within the Nairobi CBD.

Plate 2-4: Kenyatta Avenue with Parking spaces on either side of the service lane
(Source: Nairobi Metropolitan Services)

Plate 2-5: Parking spaces on the RHS of service lane converted along Kenyatta Avenue converted to NMT
(Source: Nairobi Metropolitan Services)

2.7.3 Nairobi Metropolitan Area Transport Authority - NaMATA

The transport authority established in 2017 is tasked with providing an efficient and effective public transport system within the Nairobi Metropolitan Area that consists of Nairobi City, Kajiado, Kiambu, Machakos and Murang'a counties. An efficient, integrated, and safe public transport system is important for the promotion of NMT use. The Bus Rapid Transit (BRT) framework developed by the authority highlights the importance of NMT in first and last mile connectivity and purposes to develop a comprehensive NMT network that provides seamless pedestrian connectivity making it effortless for passengers to access BRT stations and other economic hubs on foot.

The Mass Rapid Transit System Report for Nairobi Metropolitan Region (2014) identified five Bus Rapid Transit (BRT) corridors and integration nodes with the commuter rail as illustrated in Plate 2-6. The transport authority purposes to have an independent network of NMT infrastructure that incorporates walkways, cycle lanes and bicycle parking facilities strategically placed so as to encourage the use of active and public modes of transport within the Metropolitan Region.

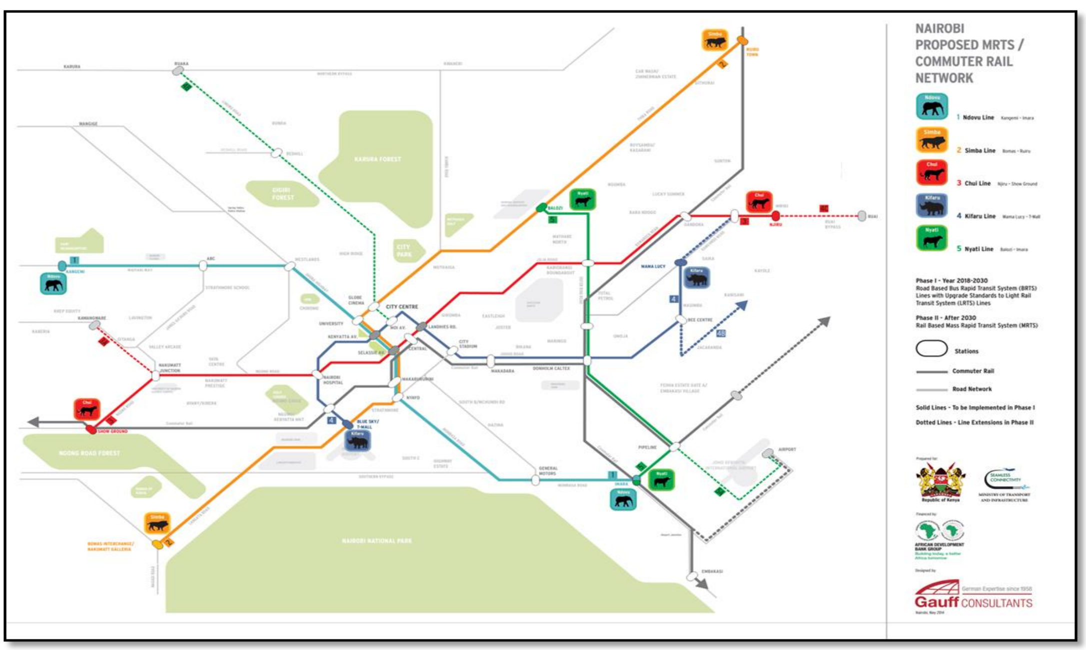


Plate 2-6: Map of MRTS Corridors for the Nairobi Metropolitan Area

(Source: MRTS Report for Nairobi Metropolitan Region, 2014)

The five BRT lines, Ndovu, Simba, Chui, Kifaru and Nyati are all at various stages of implementation guided by the BRT Design Framework by NaMATA. The recommended typical cross-section of the BRT corridors will have a median-running bus lane, general traffic lanes, cycle lanes and walkways as illustrated in Plate 2-7. It is further recommended that all corridors should have walkways on either side of the road that are at least 1.5m wide allowing for two-way movement (BRT Design Framework, 2018).

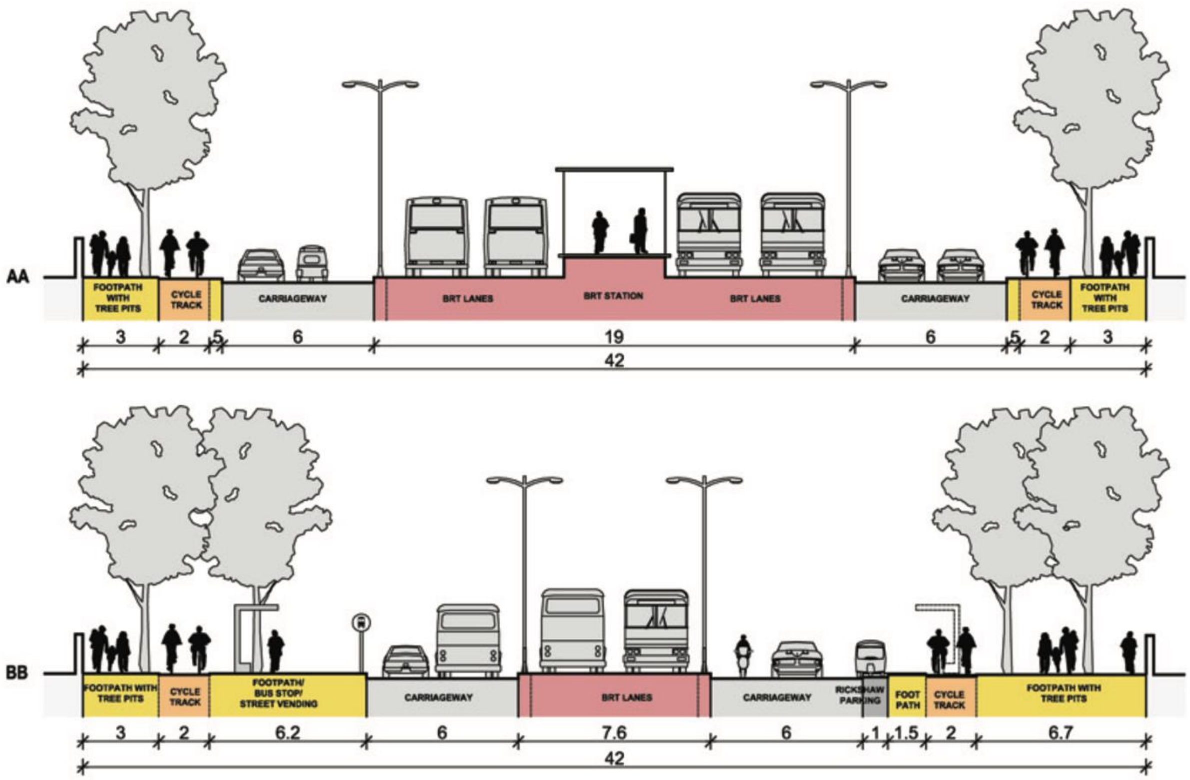


Plate 2-7: Typical Cross-section of BRT corridor

The upper figure shows the cross section at a BRT station and the lower one shows the cross section at off-station location. (All dimensions in metres).

(Source: BRT Design Framework, 2018)

2.8 CHARACTERISTICS OF NMT PAVEMENTS

It is not an easy task allowing vehicles and pedestrians to efficiently and safely share the roadway environment. The characteristics of these two modes of travel are different and yet compete for use of the same street and highway space. Establishing realistic design criteria and control for all traffic served is the most effective roadway design (ITE, 1998). The Australian Capital Territory

Standards for urban Infrastructure (2007) recommends the following principles during the design of pedestrian and cycle facilities: -

i. Safety – Conflict points should be minimised and the geometric design should reduce the threat risk of the pedestrian.
ii. Coherence – The user should have the freedom of route choice, that is continuous, easy to find and follow. The quality of works ought to be consistent.
iii. Attractiveness – The NMT network should be integrated with other modes to ensure that the community's economic activity is supported.
iv. Directness – Desire lines need to be determined so as to place the pedestrian facilities where it is most convenient and direct for the pedestrian and minimises delay.
v. Comfort – The path should be clear of obstructions, minimises steep gradients and offers a smooth ride.

The most common place to find a pedestrian is on a sidewalk and the lack of one creates particular problems for pedestrians. Well-designed sidewalks should have a relatively smooth surface, made from durable material, with good coefficient material and has the capacity to handle expected load (Charles et al, 1998). Properly designed walkways separate pedestrian from vehicular traffic providing pedestrian mobility, safety, and accessibility. It is recommended to place sidewalks on both sides of residential streets and highways where pedestrians are expected.

Concrete is the most commonly used material for pedestrian sidewalks providing the longest service life and requiring the least amount of maintenance. while asphalt is mostly used for shared use paths (FHWA, 2002).; these two materials are conventionally suitable for motorised transport and may prove to be more expensive for use in low volume pavements such as walkways. There are other pavements such as tactile, loose surfacing and split face stone that are used for footpath surfaces as highlighted in Table 2-4; also captured in the table from the New Zealand Transport Authority are the advantages and disadvantages of the various footpath surfaces used currently. The Florida Pedestrian facilities planning and design handbook (1999) recommends that walkway surfaces should be made of materials that require minimal maintenance, are not slippery when wet, are inexpensive and are usable by persons with disabilities. The use of other materials other than concrete is acceptable.

Table 2-4: Advantages and Disadvantages of various Footpath Surfaces

SURFACE	ADVANTAGES	DISADVANTAGES
Concrete	Minimal maintenance required.	Can be aesthetically displeasing.
Asphalt	If removed can easily be restored. Maintenance is inexpensive.	Associated with vehicular traffic and can be confusing to pedestrians. Can sink and cause protrusions
Tactile paving	Provides way-finding cue for the visually impaired.	Can be aesthetically displeasing.
Stone pavers and unglazed brick	Easy to replace if damaged. Easy to reset if displaced. Highly decorative.	Can create trip hazard if small units can move independently. Difficult to maintain crossfalls. Can cause vibration to users. Some pavers or joints are susceptible to moss.
Loose surfacing, such as exposed aggregate, gravel and bark	Inexpensive to install. Can be aesthetically pleasing. Can fit well in ‘rural’ environments.	Can cause severe problems for the mobility impaired if not well compacted. Requires significant maintenance commitment. Susceptible to weeds.
Cobblestones Split-face stone,	Highly decorative.	Not easily crossed by the mobility impaired or walking pedestrians wearing some fashion shoes. Susceptible to moss and weed growth.

(Source: The New Zealand Transport Authority)

2.9 SUMMARY

Plastics are a major hazard to the environment because of its disposal difficulty and recycling ensures the problems brought about by poor disposal are solved. With increasing use of bio-degradable material, increased infrastructure demand due to population increase, global warming, climate change and limited resources; use of plastic pavement as an alternative pavement material is timely.

Plastics are categorised broadly into thermoplastics and thermoset. The plastic waste generated constitutes 80 per cent thermoplastic and 20 per cent thermosets. The unique characteristic of thermoplastics allowing them to maintain their chemical properties even after subjecting them to repeated heating and cooling makes them highly recyclable. At a temperature of 140^0 – 170^0 c Thermoplastics are collected, cleaned, shredded and mixed with sand (at a ratio of 30 per cent plastic, 70 per cent sand) and moulded into plastic paving blocks. These blocks can be installed and function the same way as concrete paving blocks commonly known as cabro.

Transportation is multidimensional whose importance is historical, social, economic, political and environmental making it fundamental for the country's growth and development. With the invention of the automobile, mobility became more efficient. However, increased motorization led to increased congestion, urban sprawl, accidents, pollution (noise and air) within our urban centres. These challenges can be mitigated through shift to sustainable transport that promotes environmentally friendly modes such as walking and cycling facilitating increased accessibility and mobility within the urban centres.

Having invested heavily in car-entered approach to solve the transportation challenges, the Government of Kenya is shifting towards approaches such as land use planning, public transport planning and demand management that promote sustainable transport. The country has also formulated the supporting policy developing the integrated National Transport Policy, the Nairobi NMT policy and establishing the Nairobi Metropolitan Area Transport Authority.

Providing adequate NMT infrastructure would ensure commuters embrace use of NMT modes and counteract the negative impacts of motorisation. Walkways should be made of materials that require minimal maintenance, are not slippery when wet, are inexpensive, are usable by persons with disabilities and can bear the loading. The Institute of Transportation Engineers design and safety of pedestrian facilities manual stipulates that well-designed sidewalks should have a relatively smooth surface, made from durable material, with good coefficient material and has the capacity to handle expected load. The use of other materials other than concrete and asphalt is acceptable.

Improved accessibility and mobility within our urban areas can be achieved through provision of properly planned, designed and constructed pedestrian facilities. With climate change and global warming being emerging issues in today's world the use of conventional materials such as asphalt and concrete needs to be reconsidered and thus the need to explore the use of alternate materials such as plastic that can be friendly to the environment.

2.10 LITERATURE GAP

Plastic waste management is challenging even for wealthy nations. That notwithstanding recycling and holistic solid waste management systems are two effective and simple ways to manage solid waste. Providentially, attempts have been made to incorporate plastic waste in the manufacturer of bricks. These bricks with plastic waste as a component will eventually be able to improve plastic management while also encouraging long-term development. As a result, the use of plastic sand blocks would promote environment protection and sustainable development (Kameshwar et al, 2022).

Researches have studied how plastic waste may be combined with other raw materials to make plastic paving blocks and their resulting characteristics. Using Indian Standards - IS 1077: 1992 (Kameshwar et al, 2022) established the water absorption rate of plastic paver blocks by initially drying the specimen in the oven at a temperature of $(40 \pm 5)^0$ c to obtain dry mass, $M_{1.}$ The specimen was then immersed in water for 24 hours, removed and weighed to obtain wet mass, M_2. The water absorption rate for the blocks was nil for bricks with a plastic sand mix design ratio of 1:3, 1:4, and 1:5. Plastic paving blocks with 50 per cent, 60 per cent and 70 per cent plastic additives have a water absorption rate of 1.62, 1.47, and 1.32 respectively (Avinash et al, 2019). The average split tensile strength of the samples with a plastic sand ratio of 1:3, 1:4, and 1:5 was found to be 737.486 MPa, 804.53 MPa, and 654.25 MPa respectively. The split tensile strength of bricks increased when the percentage of plastics was reduced by up to 20 per cent, however, the split tensile strength reduced as the percentage of plastics was reduced further. This because the amount of sand used was notably more than the amount of plastic used, and there was a reduction in the bonding between plastic and sand resulting to this loss of strength (Kameshwar et al, 2022). The compressive strength of plastic sand pavers with a plastic sand ration of 1:2, 1:3, 1:4, 1:5, 1:6 was found to be 4.65 N/mm^2, 4.78 N/mm^2, 5.12 N/mm^2, 4.92 N/mm^2 and 3.17 N/mm^2 respectively (Dinesh et al, 2016). Plastic paver blocks with 40 per cent plastic additive collapsed upon application of compressive force on the specimen; for blocks with 50 per cent, 60 per cent, and 70 per cent plastic additive the compressive strength was recorded as 7.26Mpa, 12.45Mpa, 14.7Mpa respectively (Avinash et al, 2019).

This study focuses on establishing the suitability of plastic paving blocks by performing the water absorption, tensile strength and abrasion tests in accordance with South African National Standards and carrying out a purchase cost analysis to compare the cost of one square meter of plastic paving block to concrete in Kenya. The plastic waste menace has given rise to small and medium enterprises that produce roofing tiles, fencing poles and paving blocks from recycling the plastic waste. The plastic paving blocks are a revolutionary product in the highway and pavement industry but without analysis and documentation the product cannot be adopted. The results from this study aggrandizes information on the performance of the plastic paving blocks as an alternate material.

2.11 CONCEPTUAL FRAMEWORK

The independent variable for this study was the mix design ratio of the plastic paving blocks. The study performed tests on specimen manufactured with a plastic sand ratio of 1: 2.33 by weight 30 per cent plastic and 70 per cent sand.

The dependent variables of the specimen that were measured were: -

i. Water absorption rate – The amount of moisture gained was obtained by calculating mass absorbed per unit dry mass of the specimen and expressed as a percentage. (Lim 2011)
ii. Tensile Strength – The maximum stress that the plastic paving blocks could bear before breaking when subjected to stress was investigated (Aghayan and Khafajeh,2019)
iii. Abrasion rate – The ability of the plastic paving blocks upper surface to withstand being worn away by friction or rubbing (Scott et al, 2015)

iv. Purchase cost comparison – The cost of one square meter of plastic paving block was compared to that of concrete paving blocks.

CHAPTER 3 MATERIALS AND METHODS

3.1 INTRODUCTION

This study took an empirical based approach to generate the data necessary to help answer the research questions. The plastic paving blocks samples as pictured in Plate 3-1 were obtained from Corec-Kenya and assessed to determine their suitability for use in construction of NMT facilities by investigating their physical and mechanical properties in accordance with SANS 1058:2021 and the purchase cost of one square metre of plastic paving block compared to that of concrete paving block.

Plate 3-1: Plastic paving Block
(Source: Author)

3.2 ASSUMPTIONS

The mix design of the plastic paving blocks was not performed; the study assumed that the prescribed ratios of plastic and fine coarse aggregate by the manufacturer of the blocks would result in the desired characteristics. According to BS 6717: 2001 the materials used for the manufacture of paving blocks shall be at the manufacturer's discretion. In this case the mix design ratio by Corec-Kenya is 30 per cent plastic waste and 70 per cent river sand; a plastic sand ratio of 1:2.33.

3.3 DETERMINATION OF PHYSICAL AND MECHANICAL PROPERTIES

The physical and mechanical properties tested in this section are total water absorption rate, tensile strength and abrasion rate in accordance with SANS 1058:2021.

3.3.1 Total Water Absorption Test

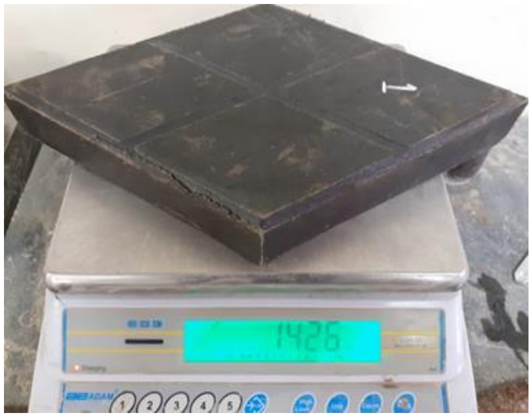
For this procedure the following apparatus were used: - ventilated drying oven capable of accommodating 6 specimens, weighing scale, brush, cloth and a flat based vessel with a capacity of at least 2.5 times the volume of the sample and a depth 50mm greater than the height of the specimen.

For preparation, the specimens were placed in the oven as shown in Plate 3-2 at a temperature of $(100 \pm 5)^0$ c for (24 ± 3) hours. The blocks were allowed to cool in the laboratory for at least 5 hours before weighing to obtain the dry mass, M_1 as shown in Plate 3-3 (a, b).

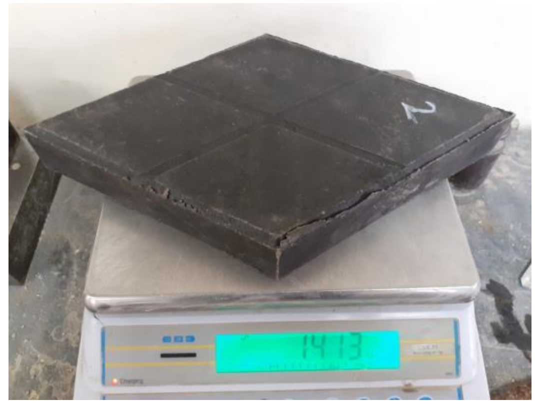
The specimens were then submerged in water at a temperature of $(20 \pm 5)^0$ c for a minimum period of 24 hours in the flat based vessel as shown in Plate 3-4. The blocks were removed from the water and a damp cloth used to remove the excess water on the surface of the blocks before weighting to obtain wet mass, M_2 as shown in Plate 3-5.

Plate 3-2: Specimens placed in oven

(Source: Author)



a



b

Plate 3-3:The dried samples are weighed to obtain M_1

(Source: Author)

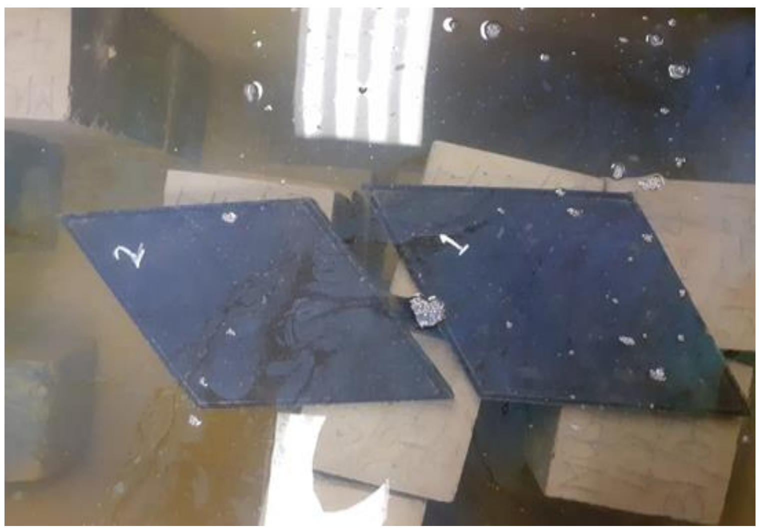


Plate 3-4: Prepared samples submerged in water

(Source: Author)

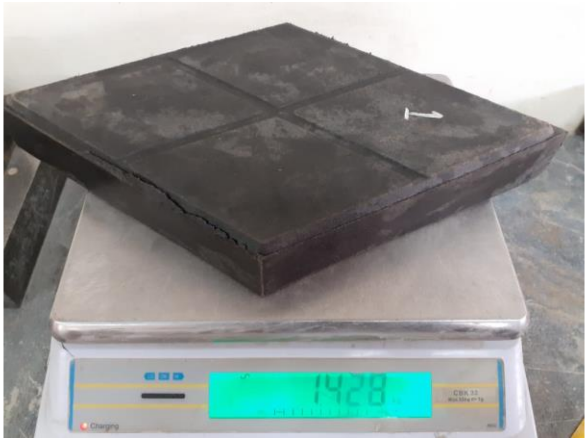
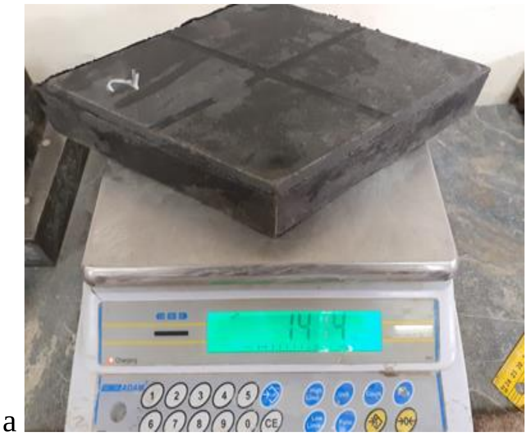
 a  b

Plate 3-5:The submerged samples are weighed to obtain M_2

(Source: Author)

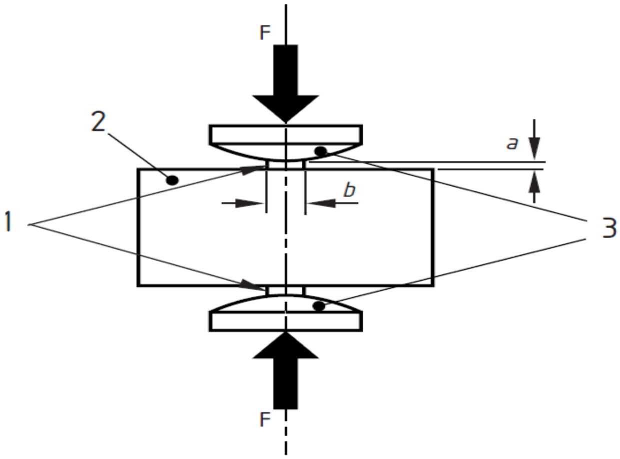
The calculation of Water absorption, W_a is as shown below

Water absorption, $W_a = \frac{(Wet\ Mass, M2 - \ Dry\ Mass, M1)}{Dry\ Mass, M1}$ x 100%

The water absorption of each specimen and the mean of the specimens tested gave the water absorption target values of the sample. According to SANS 1058:2021 the individual water absorption rate should not exceed 8 per cent and the average water absorption rate of the blocks should not exceed 6.5 per cent.

3.3.2 Measurement of Strength

For preparation, nine blocks were immersed in water for 24 ± 3 hours, wiped and placed immediately in the testing machine with the packaging pieces on the upper and bed face in contact with the bearers as shown in Figure 3-1.



KEY

1 – Packing Pieces

2 – Paving Block

3 – Rigid Bearers

Figure 3-1: Principle of Strength Testing
(Source: SANS 1058: 2021)

To obtain the failure load, P; a load was applied smoothly and progressively at a rate that increases stress of (0.05 ± 0.01) MPa/s. The area of failure, S (mm^2) was then obtained by multiplying the thickness of the block, t and the average of the two measurements of the failure length, *l* one at the top; the other at the bottom of the block and at the failure plane. The thickness, t is the average of three measurements; one at the middle and one at either end.

Therefore, S = *l* x t.

Measurement of the failure length and thickness was done to obtain the area of failure as described above as shown in Plate 3-6 (a, b, c) and the results obtained were recorded in Table 4-2.


a


b

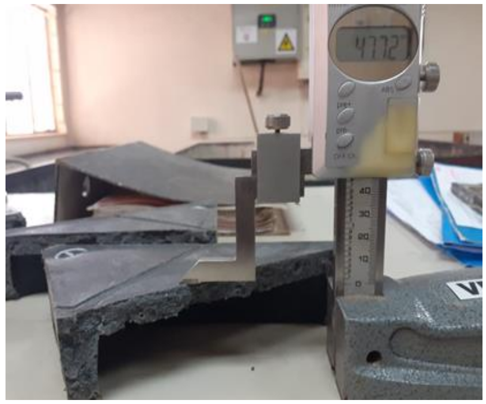
 c

Plate 3-6: Specimen tested and failure plane measured

(Source: Author)

The obtained failure area and recorded failure load were used to calculate the strength *T*, in Megapascal of the block using the following formula: -

Strength, T = 0.637 *Correction Factor, k $* {}^{Failure\ Load, P}/_{Failure\ Area, S}$

Table of correction factor, k if $t \leq 140$

Table 3-1: Value of K for $t \leq 140$

t (mm)	40	50	60	70	80	90	100	110	120	130	140
k	0.71	0.79	0.87	0.94	1.00	1.06	1.11	1.15	1.19	1.23	1.25

$k = 1.3 – 30\ (0.18 - {}^{t}/_{1000})^2$ if $140\ mm < t \leq 180\ mm$

The calculated results are tabulated in Table 4-2 and values of Strength; *T* are to the nearest 0.1MPa. The individual strength of the specimens shall not be less than 1.5Mpa and the average strength shall not be less than 2.0Mpa according to SANS 1058:2021 for class 1.

3.3.3 Measurement of Abrasion Resistance

The test was carried out by abrading the wearing (upper) face of a paving block with an abrasive material under standard conditions. The tumbler machine illustrated in Figure 3-2 is the apparatus used to carry out the abrasion resistance test. The specimens are tightly secured on the tumbler machine and subjected to abrasion by placing steel balls inside the tumbler machine and rotating it. Abrasion takes place when the upper surface of the paving block comes into contact with the rotating steel balls. A minimum of eight blocks were used and the average loss in weight recorded.

The initial mass, M_1 of the specimens was determined 30 minutes before testing as shown in Plate 3-7 (a, b) for specimen labelled 3 and 6 respectively. The specimens were then secured centrally over the cover plate to the abrasion testing (tumbler) machine with the wearing face inwards as shown in Plate 3-8. Steel balls were added to the container before securing the last block. It was ensured that all holes were covered by the test specimens.

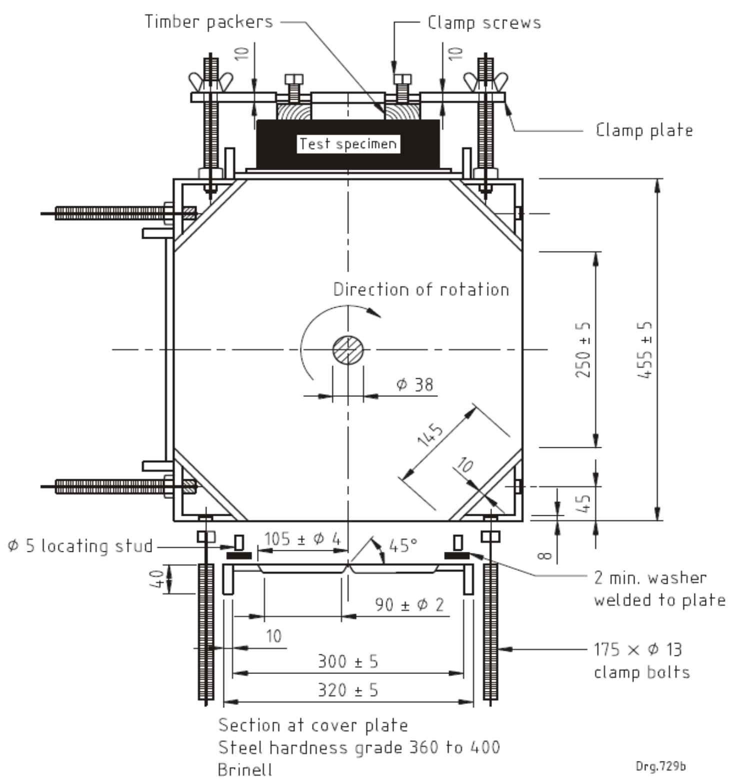


Figure 3-2: Tumbler_Section (Dimensions in mm)

(Source: SANS 1058: 2021)

- 

a

b

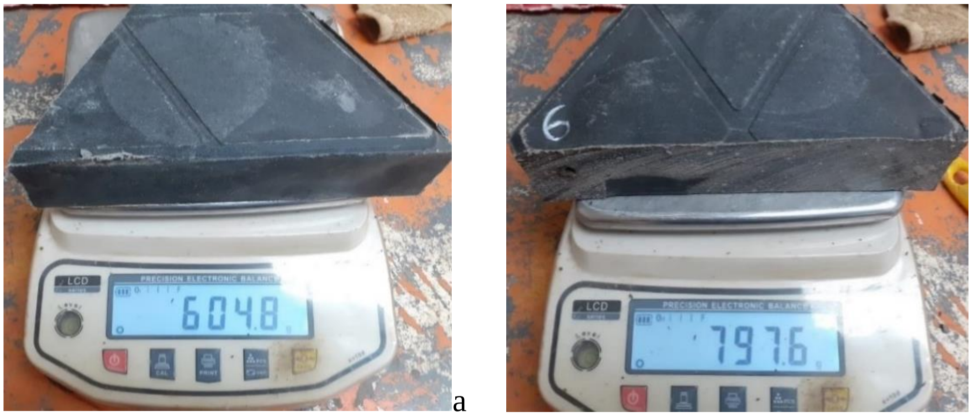
Plate 3-7: The prepared specimens are weighed before fastening on the tumbler machine to obtain M_1

(Source: Author)

Plate 3-8: The specimens fastened on the tumbler machine

(Source: Author)

The machine was run for 3600 revolutions at a rate of 60r/min. Upon completion of the revolutions the blocks were carefully detached, dusted and vacuumed to remove all loose particles and within 30 minutes of cleaning weighed to obtain mass, M_2 as in Plate 3-9 (a, b). The circular imprints indicate the area of the specimen that was in contact with the steel ball bearings in the drum and underwent the abrasion.



a b

Plate 3-9: After the test the specimens are weighed to obtain M_2

(Source: Author)

The weight loss was calculated for each specimen and average obtained for the samples tested to determine the abrasion rate.

Weight Loss = Initial Mass, M_1 – Final Mass, M_2

According to SANS 1058: 2021 the average and individual mass loss of blocks shall not exceed 15g and 20g respectively. The results of the abrasion test are recorded in Table 4-3.

3.4 PURCHASE COST COMPARISON ANALYSIS

A purchase cost comparison was carried out by enquiring and obtaining invoices attached in appendices from various production companies to undertake a purchase cost comparison for a square meter of the plastic and concrete paving blocks.

The following companies were contacted to provide cost estimates and the quotations tabulated in Table 4-4: -

1. Corec Kenya – Plastic Paving Blocks
2. Gjenge Pavers – Plastic Paving Blocks
3. Danblaq – Concrete plastic paving Blocks (Cabro)

CHAPTER 4 RESULTS AND DISCUSSIONS

4.1 WATER ABSORPTION TEST

The water absorption test is carried out to determine the ability of the sample to withstand the intended exposure conditions. Engineering(Mechanical) properties such as strength, creep and permeability are directly influenced by the rate of uptake of the liquids by the sample.

The water absorption test was performed on six plastic blocks from the sample to obtain their individual water absorption rate using the formula: -

Water absorption, $W_a = {(\text{Wet Mass}, M2 - \text{Dry Mass}, M1)}/{\text{Dry Mass}, M1}$ x 100%

The average water absorption rate was then obtained and the results of the water absorption test tabulated in Table 4-1.

Table 4-1: Water absorption rate test results

S/No	Dry Mass, M_1 (g)	Wet Mass M_2 (g)	$M_2 - M_1$	$(M2 - M1)/M1$	$(M2 - M1)/M1$ x 100%	Water Absorption, W_a (%)
WA1	1426	1428	2	0.0014	0.14	0.1
WA2	1413	1414	1	0.0007	0.07	0.1
WA3	1418	1421	3	0.0021	0.21	0.2
WA4	1367	1368	1	0.0007	0.07	0.1
WA5	1425	1428	3	0.0021	0.21	0.2
WA6	1429	1430	1	0.0006	0.06	0.1
					Total	0.8
					Average	0.1

The water absorption rate of each specimen ranged between 0.1 and 0.2 per cent meaning there was very minimal water infiltration by the plastic paving blocks and does not exceed the recommended individual water absorption rate of 8 per cent. The total absorption rate of the six blocks was 0.8 per cent bringing their average water absorption rate to 0.1 per cent and does not exceed the recommended rate of 6.5 per cent. Therefore, the water absorption rate of the plastic paving blocks was within the stipulated parameters. These findings imply that the plastic paving blocks have a low permeability and can be used in damp areas without compromising other properties such as strength.

4.2 STRENGTH TEST

The strength test gives a direct indication of a sample's capacity to endure loads in structural applications from compressive, tensile, or shear forces and in some instances a combination of these. The test is used for three purposes research, quality control and assurance, and determining in place concrete strength. In research the strength test is instrumental in determining the effects of various components or mixture quantities on the strength of the samples. A sample's resistance to cracking is determined by performing the tensile strength test. The strength test was performed on nine plastic blocks from the sample; the results obtained were derived from the formula strength T, in megapascal of the block = 0.637 * k*P/S and the results tabulated in Table 4-2 below: -

Table 4-2: Tensile Splitting Test Results

S/No.	Failure Load, P (N)	Thickness, t (mm)	Failure Length, l (mm)	Failure Plane Area, S (mm2)	Correction Factor, K	Strength, T (Mpa)
S1	38200	46	196	9016	0.79	2.1
S2	29700	46	184	8464	0.79	1.8
S3	32000	47	189	8883	0.79	1.8
S4	29800	47	191	8977	0.79	1.7
S5	28400	46	190	8740	0.79	1.6
S6	28200	46	186	8556	0.79	1.7
S7	36700	46	189	8694	0.79	2.1
S8	42300	46	190	8740	0.79	2.4
S9	43600	47	189	8883	0.79	2.5
					Total	17.7
					Average	2.0

The results obtained depend on the specimen shape, size, preparation and loading method. For this study the specimens were cut into smaller sizes for them to fit into the strength testing machine.

The strength of the individual specimens' ranges between 1.6 – 2.5 Megapascals. SANS 1058:2021 recommends that the individual strength of the tested specimen should not be less than 1.5MPa. From the results tabulated in Table 4-2 all the specimens tested satisfied this parameter. The average tensile strength is 2.0MPa which was just within the recommended average of 2.0Mpa. These findings indicate that the plastic paving blocks can be used on low traffic pavements.

4.3 ABRASION TEST

Abrasion is defined as wear due to hard particles or protuberances forced against and moving along a solid surface according to American Society for Testing and Materials – ASTM (2006) Terminology relating to erosion and wear (G40). The American Concrete Institute further defines abrasion resistance as the ability of a surface to resist worn away by rubbing and friction. Road surfaces are susceptible to deterioration due to the abrasive action of environmental and man-made factors such as traffic. Carrying out the abrasion test serves to (1) evaluate, predict or accept the quality of the surfaces (2) compare various types of surfaces under simulated abrasion conditions (3) evaluate specific effects of variables such as concrete-making materials, curing, finishing procedures, surface hardeners, or coating materials and (4) verify products or systems to meet specifications. In this study the abrasion resistance test was carried out to verify the plastic paving blocks meet the abrasion rate specification as stipulated by SANS 1058: 2021.

The abrasion test was performed on eight blocks from the sample and the results analysed and tabulated in Table 4-3 indicating the initial mass M_1 before the test was carried out, Final mass M_2 after the abrasion test was carried out and the difference between initial and final mass of each specimen.

Table 4-3: Abrasion Rate Test Results

S/No	Initial Mass, M_1 (g)	Final Mass, M_2 (g)	Weight Loss (g) $M_1 - M_2$
AB1	787.1	787.1	0
AB 2	831.8	831.7	0.1
AB 3	604.9	604.8	0.1
AB 4	856.4	856.4	0
AB 5	592.6	592.5	0.1
AB 6	797.7	797.6	0.1
AB 7	595	594.7	0.3
AB 8	569.4	569.4	0
		Total	0.7
		Average	0.09

The individual weight loss of the specimens ranges between 0 – 0.3g and does not exceed the recommended 20g. The average mass lost for the specimen was 0.09g and does not exceed the recommended weight loss of 15g. These findings indicate that the plastic paving blocks can with stand surface deterioration from high abrasive action.

4.4 PURCHASE COST COMPARISON ANALYSIS

Three companies were identified and contacted for a quotation of the products they manufacture and specialize in. The purchase cost of the products varies because of the difference in production cost of the commodities. Production cost differ because of geographical location, specialisation in production and efficiency of labour. Each company specialises in the production of their commodity in which its comparative cost of production is the least.

Three companies Corec Kenya, Gjenge pavers and Danblaq provided their quotation for these study and the data in tabulated in Table 4-4. The price of one square meter of plastic paving block retails at Kes. 800 which translates to $6.79 at Corec Kenya (Appendix A) and at Gjenge Pavers based on the characteristic of the block it ranges from Kes. 850 – 1250 which translates to $7.21 – 10.60 (Appendix B). Concrete paving blocks retail at Kes. 750 which translates to $ 6.36 according to quotation obtained from Danblaq (Appendix C).

Table 4-4: Cost Analysis Table

S/no.	Company	Material used	Characteristic	Price (Ksh. per m^2)
1.	Corec Kenya	Plastic	44mm thick	800
2.	Gjenge Pavers	Plastic	Natural	850
			Colored	970
			Grey	1100
			White	1250
3.	Danblaq	Concrete	40mm thick	750

The process of manufacturing the plastic paving block is not yet as efficient as that of manufacturing the concrete paving blocks. For the two companies Corec and Gjenge they fabricated their machinery which requires heavy initial capital. The purchase cost of the plastic and concrete paving blocks compares well because as the production process is streamlined the production cost is bound to reduce consequently lowering the purchase cost of the plastic paving blocks. This finding indicates that the purchase cost of one square meter of plastic paving block costs 40¢ more than concrete paving blocks. This slight difference in price may see early adapters of the product purchasing and recommending to other users thereby increasing the rate of adaptation within the industry.

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The following conclusions were drawn from the study: -

i. The physical and mechanical properties of the plastic paving blocks were within the specifications stipulated in SANS 1058:2021.

   The physical and mechanical properties that were investigated were water absorption rate, tensile strength and abrasion rate. The individual water absorption rate for the six (6) plastic paving blocks that were tested was minimal ranging between 0.1 – 0.2 per cent against the recommended rate of 8 per cent and the average water absorption rate was within the recommended 6.5 per cent at 0.1 per cent. The tensile strength test was performed on nine (9) plastic paving blocks. The recommended individual strength of the specimen was 1.5Mpa and for each specimen the recorded strength ranged between 1.6 – 2.5 Mpa. The average tensile strength of the sample is 2.0MPa which was also within the recommended average of 2.0Mpa. Eight (8) plastic paving blocks were tested to investigate the abrasion rate of the plastic paving blocks. The recorded individual weight loss of the specimens ranged between 0 – 0.3g and does not exceed the recommended 20g. The average mass lost for the specimen was 0.09g and does not exceed the recommended weight loss of 15g.

ii. The purchase cost of one square meter of plastic paving block is 40¢ (Kes. 50) more than that of concrete paving blocks.

5.2 RECOMMENDATION

This study makes the following recommendations.

5.2.1 Recommendation from this Study

This study recommends that plastic paving blocks can be used for low traffic pavements including Non-Motorised Transport Facilities (walkways and cycle).

This is because the water absorption rate, strength and abrasion rate of the plastic paving blocks were all within the specifications stipulated by SANS 1058:2021.

5.2.2 Recommendations for Further Studies

i. Further studies are needed to establish the appropriate mix design for the plastic paving blocks and standards set so that engineers have a reference point to ensure consistency. This is because despite the plastic paving blocks being within the recommended strength specifications by SANS 1058:2021, it is important to note the disparity in the individual strength values indicating the possibility of an inconsistency in the design mix for the plastic paving blocks by the manufacturer.

ii. Further studies are needed to undertake a comprehensive cost analysis factoring in the cost of individual elements in production process for both the plastic and concrete paving blocks to determine a purchase cost that is reasonable and fair to both the buyer and manufacturer and to establish the economic impact of recycling plastic waste. This is because the purchase cost of the plastic paving blocks is slightly more however, factoring in the environmental impact from recycling of plastic waste, the ultimate economic impact of using the plastic paving blocks may outweigh that of the concrete paving blocks despite the plastic paving blocks costing more.

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APPENDICES

7.1 APPENDIX A: Quotation 1 - Corec Kenya

Continental Renewable Energy Company Limited
22329 - 00400
Nairobi
0700939645
ceo@corec.co.ke

corec
Turning waste plastic in to building hardware

Estimate

ADDRESS
Abbigael Wanjiru

ESTIMATE NO. 1349
DATE 02/11/2020
EXPIRATION DATE 02/11/2020

DATE	ACTIVITY	DESCRIPTION	QTY	RATE	AMOUNT
02/11/2020	**COREC DRIVEWAY BLOCK**	Size: 200 mm x 200 mm x 50mm (thickness) Weight: 1.6 kgs Number in a square meter: 20	20	40.00	800.00

TOTAL **Ksh800.00**

7.2 APPENDIX B: Quotation 2 – Gjenge Pavers

7.3 APPENDIX C: Quotation 3 – Danblaq Limited

QUOTATION

DANBLAQ

Tel: 0702 849 022 / 0733 127 283 | Email: sales@danblaq.co.ke | danblaqltd@gmail.com
Accra Road, Baicki House, 3rd Floor, Room 301 | P.O. Box 30359 - 00200 Nairobi

TO: Yahya Car Sales

DATE: 17.05.2019

YAHYA CAR SALES(250Sqm CABRO CAR PARKING)

Sr. No	Description	Qty.	Unit	Rate (Kshs.)	Amount (Kshs.)
1.	Vumbi	20	Tonnes	2,000	40,000
2.	Murram	26	Tonnes	500	13,000
3.	Riversand	12	Tonnes	2,200	26,400
4.	Cement	10	Bags	700	7,000
5.	Cabro	250	Sqm	690	172,500
6.	Logistics	1	Pcs	20,000	20,000
7.	Compactor	5 -10	Tonnes	15,000	15,000
8.	Labour and Msc	1	Pcs	100,000	100,000
				SUBTOTAL	393,900
				VAT	63,024
				TOTAL	456,924

TERMS AND CONDITIONS

- A 50% downpayment is required for work to proceed. A 50% payment upon completion
- Kindly do not hesitate to contact us incase you require further clarification.

QUOTATION NO. 512