



**KENYATTA UNIVERSITY**  
**DEPARTMENT OF ARCHITECTURE & INTERIOR DESIGN**  
**ARC 602: ARCHITECTURAL RESEARCH PROJECT**

# **BUILDING FROM PLASTIC WASTE: OPPORTUNITIES AND LIMITATIONS IN KENYA.**

**MARYAM WANGECI**

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*This dissertation is submitted to the Department of Architecture and Interior Design at Kenyatta University in partial fulfillment for the degree of  
Bachelor of Architecture (B. Arch)*



*Figure 1 Construction using plastic blocks by Timao Group. Source Author 2023.*

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**“In waste you will find the  
Blueprint  
Of tomorrow’s architecture”.**

*Maryam Wangeci*

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## DECLARATION

This is my original work and to the best of my knowledge has not been presented for the award of a degree in any other institution.

Author: Maryam Wangechi Mwangi

Signature:

Date:

Supervisor: Arch. Franklin Mwangi

Signature:

Date:

Year coordinator: Prof. Alfred Omenya

Signature:

Date:

Chairperson Department of Architecture: Arch Aidah Munano

Signature:

Date:

---

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---

## DEDICATION

I dedicate this thesis to God, the source of all wisdom and knowledge. He knows what the research will lead to, the opportunities and how it aligns to my life's purpose. I thank Him for His guidance, grace, and provision throughout this journey. I pray this work is used for the benefit of His creation.

I also dedicate this thesis to my fellows in the construction industry, so as to provide some valuable guidance. I hope that it inspires and challenges us to rethink and transform the way they use and manage plastic waste as a building material.

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## ABSTRACT

Plastic is one of the most ubiquitous and versatile materials in the modern world. It has revolutionized many aspects of human life, from medicine and technology to fashion and entertainment. However, plastic also poses a serious environmental and social challenge, as it is mostly used for single-use products that are discarded after a short period of use. Every year, millions of tons of plastic waste are generated and discarded, causing pollution, harming wildlife and affecting human health. One of the possible ways to address the plastic waste is to use it as a building material. Plastic waste can be transformed into various products, such as bricks, tiles, panels and blocks, that can be used for constructing houses and other structures. This approach has several benefits, such as reducing plastic pollution, saving energy and natural resources, creating employment and income opportunities, and providing cheap and resilient housing. However, there are also challenges and limitations, such as technical, economic, social, and environmental factors, that need to be considered and overcome.

This thesis therefore aims to explore the feasibility and potential of building from plastic waste in Kenya, a country that faces the plastic waste crisis and to identify the best practices and recommendations for its implementation. A mixed-methods research design is used, combining literature review, case studies, interviews, surveys, and experiments, to collect and analyze data from various sources and perspectives. It is found that building from plastic waste is a viable and promising solution for Kenya, but it also requires careful planning, design, regulation, and monitoring, to ensure its quality, safety, performance, and acceptance. A framework and a roadmap for implementing and scaling up this solution in Kenya and other similar contexts is provided. The thesis contributes to the existing knowledge and practice of building from plastic waste, and offers insights and implications for policy makers, practitioners, researchers, and communities.

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# TABLE OF CONTENTS

<b>ACKNOWLEDGEMENTS</b> .....	<b>5</b>
<b>DEDICATION</b> .....	<b>6</b>
<b>ABSTRACT</b> .....	<b>7</b>
<b>CHAPTER 01:</b> .....	<b>15</b>
<b>INTRODUCTION</b> .....	<b>15</b>
1.1: BACKGROUND AND CONTEXT.....	16
1.2: PROBLEM STATEMENT.....	21
1.3: RESEARCH AIM AND OBJECTIVES.....	22
1.4: RESEARCH QUESTIONS.....	22
1.5: SCOPE AND LIMITATIONS .....	23
1.6: ASSUMPTION OF STUDY .....	23
1.7: JUSTIFICATION OF THE STUDY .....	23
1.8: SIGNIFICANCE OF THE STUDY .....	24
1.9: STRUCTURE OF THE THESIS.....	25
1.10: DEFINITION OF OPERATIONAL TERMS.....	26
<b>CHAPTER 02:</b> .....	<b>28</b>
<b>LITERATURE REVIEW</b> .....	<b>28</b>
2.1: PLASTIC WASTE: SOURCES, IMPACTS AND MANAGEMENT .....	29
2.2: WORLD VIEW OF LITERATURE .....	38
2.3: PLASTIC WASTE AS A BUILDING MATERIAL: TYPES, PROPERTIES AND APPLICATIONS .....	43
2.4: BENEFITS AND CHALLENGES OF BUILDING FROM PLASTIC WASTE.....	69
2.5: PLASTIC WASTE AND ARCHITECTURE .....	74
2.6. CONCEPTS IN PLASTIC WASTE AND ARCHITECTURE.....	78
2.7: SUMMARY OF THE LITERATURE.....	89
2.8: THEORETICAL AND CONCEPTUAL AND FRAMEWORK .....	90

<b>CHAPTER 03:</b> .....	<b>94</b>
<b>PRECEDENT STUDIES</b> .....	<b>94</b>
3.1: SELECTION CRITERIA AND METHODOLOGY .....	96
3.2: INTERNATIONAL PRECEDENTS .....	97
3.3: REGIONAL PRECEDENTS .....	103
3.4: LOCAL PRECEDENTS .....	106
3.5: PRECEDENT STUDY ANALYSIS AND COMPARISON .....	107
<b>CHAPTER 04:</b> .....	<b>109</b>
<b>RESEARCH METHODS</b> .....	<b>109</b>
4.1: RESEARCH DESIGN AND APPROACH .....	110
4.2: DATA COLLECTION METHODS AND TOOLS .....	111
4.3: DATA ANALYSIS METHODS AND TOOLS .....	112
4.4: ETHICAL CONSIDERATIONS AND VALIDITY .....	112
<b>CHAPTER 05:</b> .....	<b>113</b>
<b>FIELD DATA</b> .....	<b>113</b>
<b>PRESENTATION AND ANALYSIS</b> .....	<b>113</b>
<b>TIMAO GROUP, PLASTIC BLOCKS</b> .....	<b>114</b>
5.1: FINDINGS 1 .....	114
5.2: ANALYSIS OF DATA 1 .....	124
<b>GJENGE MAKERS, PLASTIC PAVERS</b> .....	<b>127</b>
5.3: FINDINGS 2 .....	127
5.3: ANALYSIS 2 .....	129
<b>PERSPECTIVES, ATTITUDES, OPINIONS</b> .....	<b>130</b>
5.4: FINDINGS AND ANALYSIS 3 .....	130
5.5: DISCUSSION OF THE FINDINGS .....	136
5.6: DESIGN CONSIDERATIONS BASED ON THE FINDINGS .....	140
<b>CHAPTER 06:</b> .....	<b>143</b>

**CONCLUSIONS.....143**

**AND .....143**

**RECOMMENDATIONS.....143**

6.1: SUMMARY OF THE MAIN FINDINGS ..... 144

6.2: IMPLICATIONS FOR THEORY AND PRACTICE..... 144

6.3: RECOMMENDATIONS FOR FUTURE RESEARCH ..... 146

6.4: PERSONAL REFLECTIONS..... 148

6.5: CONCLUDING REMARKS ..... 150

**REFERENCES.....151**

**APPENDIX 1- DATA COLLECTION TOOLS.....155**

SEMI STRUCTURED INTERVIEW-STAKEHOLDERS ..... 155

OPEN ENDED QUESTIONNAIRE-GJENGE MAKERS ..... 156

SITE PHOTOGRAPHS..... 157

SECONDARY DATA ON GJENGE MAKERS ..... 158

**LAST PAGE .....159**

## LIST OF FIGURES

Figure 1 Construction using plastic blocks by Timao Group. Source Author 2023.....	2
Figure 2:Source National Geographic Album 2019.....	15
Figure 3: A great bowerbird in Queensland, Australia, uses plastic toys, broken glass, and other human waste to adorn its home. Source: <a href="https://images.app.goo.gl/9523PSXsJr3Wa64n9">https://images.app.goo.gl/9523PSXsJr3Wa64n9</a> .....	16
Figure 4: Heap of plastics, source: <a href="https://images.app.goo.gl/HdBS6gpmQDkX5VG27">https://images.app.goo.gl/HdBS6gpmQDkX5VG27</a> .....	16
Figure 5: A pair of curious Rhesus Macaques inspect a discarded plastic bottle outside the Pashupatinath, Temple in Kathmandu, Nepal, source: <a href="https://images.app.goo.gl/Kbgmfao1VhyaGEew6">https://images.app.goo.gl/Kbgmfao1VhyaGEew6</a> .....	17
Figure 6: Worldwide production of plastic .....	18
Figure 7: Printer cartridges have been washing up on European beaches since early 2014, after they spilled off a ship during an Atlantic storm, source: <a href="https://www.mandy-barker.com/commissions">https://www.mandy-barker.com/commissions</a> .....	19
Figure 8: Shavings from various fabrication or drilling processes, source: <a href="https://www.mandy-barker.com/commissions">https://www.mandy-barker.com/commissions</a> .....	19
Figure 9: Every piece of plastic here was found in the stomach of a single albatross chick. Laid bare outside the bird they killed, the plastic pieces—from the bottle caps in the top row to the tiny fragments along the bottom—all represent “parts of something” <a href="https://www.mandy-barker.com/commissions">https://www.mandy-barker.com/commissions</a> .....	19
Figure 10: Scenario of plastic waste management. ....	20
Figure 11: The following are the proposed targets to be achieved by 2030 in Kenya: - KPP .....	20
Figure 12:Plastic as wealth. Source Bing 2023.....	28
Figure 13Fate of plastic waste. UNEP 2016 .....	29
Figure 14Early use of plastic NATGEO ALBUM 2019.....	30
Figure 15: Statistics around plastic waste management in Kenya. Source KPP .....	33
Figure 16: Dumpsite in Kenya-Remi 2018.....	33
Figure 17: Effects on Plastic pollution on ocean life,Source Natgeo 2023 .....	33
Figure 18: Waste Management Process. Source: (Plastindia Foundation, 2019).....	34
Figure 19: Plastic recyclability guidelines by KPP 2023.....	35
Figure 20: PET and HDPE plastics recyclability guidelines .....	37
Figure 21 Flow of plastic Maimuna Shehu 2019 .....	43
Figure 22: Thermoplastic categorization ( <a href="https://community.preciousplastic.com/academy/plastic/basics">https://community.preciousplastic.com/academy/plastic/basics</a> .....	43
Figure 23: Recycling potential of the various types of plastics.....	44
Figure 24: Classification of different types of plastics and suitable applications: Environmental Science and Pollution Research 2022 .....	44
Figure 25 Stages for application in building materials.Source Plastindia 2020 .....	45
Figure 26 Circular economy flow Source Plastindia 2021.....	46
Figure 27: Uses of plastic in the construction industry currently .....	47
Figure 28: Bottle school Guatemala-Source Plastindia 2023.....	48
Figure 29: United Bottle (New York, Copenhagen and Zurich): type sheet; Casas de las botellas (Argentina): type sheet. ....	50
Figure 30: Methodology chart .....	51

Figure 31: Proposed construction method: Arrangement of the bottles, creation and binding of the brick; Positioning of the bricks.....	53
Figure 32: WoBo Summer House, Netherlands, 1965; Bottle Houses, Canada, 1980-1984 Casa di Bottiglie, Italy, 1999.....	54
Figure 33: Proposed construction method: Design choices; Construction of the base of the wall.....	55
Figure 34: Proposed construction method: Preparation of stiffeners; Creation of the sleeper for the covering; Realization of a possible finish .....	55
Figure 35: Material design process .....	56
Figure 36How to make Plastic thread from PET.Source Maimunah 2019.....	56
Figure 37: Phase one of material design.....	56
Figure 38 Figure 39How to make Plastic panel from PET.Source Maimunah 2019.....	58
Figure 40Process continued Maimunah 2019 .....	59
Figure 41Plastic panel quality test.Mimunah 2019 .....	60
Figure 42: Classification of PET building component. A-sheet B-Composite.....	60
Figure 43: Chosen grid for the panel geometry .....	60
Figure 44: Panel configuration options.....	61
Figure 45: Shredding HDPE to use as insulation. ....	62
Figure 46: Wooden frame-work and composite plastic facade building component .....	62
Figure 47: Panel connection options .....	63
Figure 48: Option 5(picked option).....	63
Figure 49: Grid system and elevation .....	64
Figure 50: Exploded axonometric view of the building system .....	64
Figure 51: Building system components .....	65
Figure 52: Concrete base with wood panel insulating it.....	65
Figure 53: Optimal climate house in Kuchingoro IDP camp .....	65
Figure 54: Overhang dimension .....	65
Figure 55: Bacha C configuration .....	66
Figure 56: Bacha B configuration .....	66
Figure 57: Section through Bacha B configuration .....	66
Figure 58: Section through Bacha A configurat .....	66
Figure 59: Section through Bacha C configuration .....	66
Figure 60Panel construction Maimunaah 2019.....	67
Figure 61Panel Construction Source Maimuna 2019 .....	68
Figure 62 Method of filling the plastic bottles for using in the building .....	70
Figure 63 Brittleness characteristic of the brick .....	71
Figure 64 Green buildings built using plastic bottles.....	71
Figure 65 Taxonomies of waste .....	74
Figure 66A community collection center,India 2016.....	77
Figure 67Global Environment Facility. (2018). Plastic management system improves livelihoods of Bhopal women, helps the environment. Accessed 24 Sep. 2019 .....	77

Figure 68 Artist Impression of Zero waste urban design .....	83
Figure 69 From wasted landscapes to waste flows. ....	84
Figure 70: Waste scapes characterization model. ....	84
Figure 71 2019 Waste architecture Platform workshop.....	86
Figure 72 : Model created by arranging a collection of irregular rectangular elements.....	86
Figure 73 : It is possible to arrange demolition debris into "holding patterns." Maybe architects and urbanists can find temporary uses for this material instead of grinding it up and throwing it in the trash. By preserving patterns, future generations will be able to gather resource libraries for brand-new buildings. ....	87
Figure 74 Waste architecture Platform workshop.....	88
Figure 75 Figure 1. (a) Waste hierarchy principle according to the Waste and Climate Change Strategy Framework of the United Nations Environmental Programme [14]; (b) waste as a secondary resource (adapted from Chang and Pires [1]). In both diagrams, pre-use, use, and post-use phases appear in orange, green, and blue, respectively.....	90
Figure 76 Circular Economy flow chart. Source Plastindia 2018 .....	91
Figure 77 Sustainable Development Goals (United Nations, 2015) Colors identifies the ones which are aligned with the research Plastic Architecture.....	92
Figure 78 Conceptual framework diagram .....	92
Figure 79 Construction with plastic bottles in Nigeria, Source BBC 2008 .....	94
Figure 80 Applications of plastic in Architecture at a glance. Source Plastindia 2019 .....	96
Figure 81 Children making money filling bottles may one day be able to attend a school to be built on the estate .....	104
Figure 82 Bottles from hotels and restaurants .....	104
Figure 83 Kubik school. Source Kubik website 2019.....	106
Figure 84 Gjenge makers pavers in a school. Source Gjengemakers website 2021 .....	106
Figure 85 :Crushed plastic pellets. Source Author 2023 .....	109
Figure 86 Methodology chart .....	110
Figure 87 Draft work. Source Author 2023 .....	113
Figure 88 D.CONSTRUCTION TECHNOLOGY .....	117
Figure 89 Analysis of Gjenge makers data-Summary, Source Author .....	129
Figure 90 Stakeholder mapping. Source Author 2023.....	130
Figure 91 Calculation of Conventional Brick Cost-source author 2023 .....	133
Figure 92 Calculation of Plastic brick cost. Source Author 2023 .....	134
Figure 93 Source-Author 2023.....	137
Figure 94 Source Author 2023 .....	138
Figure 95 Source Author 2023 .....	139
Figure 96 Location Map Source Author 2023 .....	140
Figure 97 Existing site Source SWM report 2023.....	141
Figure 98 Proposed Site Landscaping. Source SWM 2023.....	141
Figure 99 Source Author 2023 .....	141
Figure 100 Source Author 2023 .....	142

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Figure 101:Visual representation of a waste facility. Source Bing 2023..... 143

Figure 102 Figure 103Implementation model Source Author 2023 ..... 145

Figure 104 Research Plan Source Author 2023..... 149

Figure 105Site study pictures. Source Author 2023 ..... 157

## CHAPTER 01:

# INTRODUCTION

*This chapter introduces the topic of using plastic waste as a construction material in Kenya, a country that faces the plastic waste crisis. It provides the background, problem statement, research objectives, questions, significance, assumption, scope and limitation of the study. It also defines the main concepts and terms used in the study, such as plastic waste, construction material, circular economy, waste management*



Figure 2:Source National Geographic Album 2019

## 1.1: BACKGROUND AND CONTEXT

Plastics are synthetic polymers made from fossil fuels that have revolutionized many aspects of human life since the late nineteenth century. They are versatile, durable, lightweight, and cheap, making them suitable for a wide range of applications, from packaging and medical devices to construction and transportation. However, they also pose a serious environmental and social problem, as they are mostly used for single-use products that are discarded after a short period of use. Plastics can take hundreds of years to decompose, and they often contain harmful additives that can leach into the environment. They are also a major source of marine pollution, as they are carried by rivers and winds into the oceans, where they harm wildlife and ecosystems.



Figure 3: A great bowerbird in Queensland, Australia, uses plastic toys, broken glass, and other human waste to adorn its home. Source: <https://images.app.goo.gl/9523PSXsJr3Wa64n9>



Figure 4: Heap of plastics, source: <https://images.app.goo.gl/HdBS6gpmODkX5VG27>

The global production of plastics has increased exponentially, from 2.3 million tons in 1950 to 448 million tons by 2015. Production is expected to double by 2050<sup>1</sup>. Every year, about 8 million tons of plastic waste escapes into the oceans from coastal nations. That's the equivalent of setting five garbage bags full of trash on every foot of coastline around the world.

The plastic waste crisis is closely linked to the issues of growing human population, urbanization, housing shortage and social inequality. As more people move to urban areas, especially in less-wealthy

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<sup>1</sup>R. Geyer, J. R. Jambeck, and K. L. Law, 'Production, Use, and Fate of All Plastics Ever Made', Science Advances, 3/7 (published online 2017), <<https://doi.org/10.1126/sciadv.1700782>>



Figure 5: A pair of curious Rhesus Macaques inspect a discarded plastic bottle outside the Pashupatinath, Temple in Kathmandu, Nepal, source:

<https://images.app.goo.gl/Kbgmfao1VhyaGEew6>

regions of Africa and Asia, the demand for affordable and convenient products and services increases, leading to more consumption of single-use plastics. However, many urban areas lack adequate waste management systems and infrastructure, resulting in plastic littering and dumping in open spaces, waterways, and landfills<sup>2</sup>.

According to UN-Habitat, an estimated 60% of people living in urban areas of Africa are in informal settlements, where access to basic services and decent housing is limited<sup>3</sup>. In sub-Saharan Africa alone, the immediate need for low-cost housing is 160 million units, and this is expected to increase to 360 million by 2050 due to rapid urbanization<sup>4</sup>. However, conventional building materials such as cement, steel, and wood are expensive, scarce, and environmentally damaging<sup>5</sup>.

One of the potential ways to address the plastic waste is to use plastic waste as a building material.

Plastic waste can be melted, molded, or mixed with other materials to create bricks, tiles, panels, blocks, and other construction products. Some of the benefits of using plastic waste as a building material are that it is durable, lightweight, water-resistant, fire-resistant, and low-cost. Some of the challenges are that it may release toxic gases when heated, it may not meet the standards and regulations of the construction industry, and it may not be aesthetically pleasing or culturally acceptable.

**Plastic production and consumption:** The global production of plastics has increased exponentially, from 2.3 million tons in 1950 to 448 million tons by 2015<sup>6</sup>. Production is expected to double by 2050. Single-use plastics account for 40 percent of the plastic produced every year, and many of them are used for packaging and discarded after a few minutes of use.

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<sup>2</sup> J. R. Jambeck et al, 'Plastic Waste Inputs from Land into the Ocean', *Science*, 347/6223 (published online 2015), < <https://doi.org/10.1126/science.1260352> >. accessed 10 Dec 2023. 768-771.

<sup>3</sup> UN-Habitat, 'World Cities Report 2020: The Value of Sustainable Urbanization | Un-habitat' [website] (n.d.), < <https://unhabitat.org/world-cities-report-2020-the-value-of-sustainable-urbanization> > .

<sup>4</sup> Ibid

<sup>5</sup> United Nations Environment Programme, 'Sand and Sustainability: Finding New Solutions for Environmental Governance of Global Sand Resources' [website] (2019), < <https://wedocs.unep.org/20.500.11822/28163> > .

<sup>6</sup> National Geographic, 'The World's Plastic Pollution Crisis Explained' [website] (n.d.), < <https://education.nationalgeographic.org/resource/worlds-plastic-pollution-crisis-explained/> > .

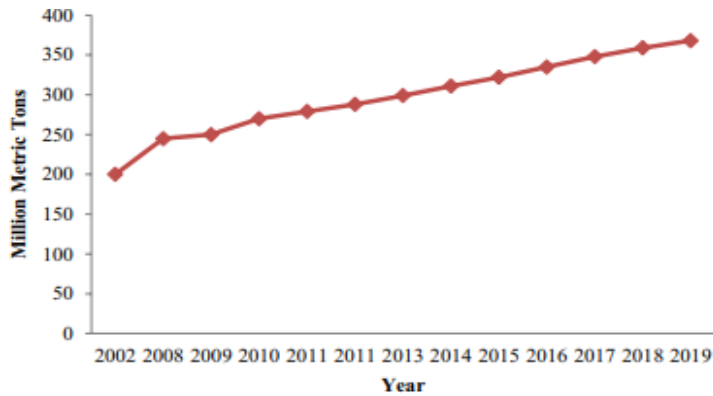


Figure 6: Worldwide production of plastic

**Plastic pollution and its impacts:** Every year, about 8 million tons of plastic waste escapes into the oceans there are five islands of plastic floating in the oceans, the largest of these, in the Pacific of about 80,000 tons<sup>7</sup>. Plastic pollution is most visible in developing Asian and African nations, where garbage collection systems are often inefficient or nonexistent. The top 10 countries that contribute the most to ocean plastic pollution are China, Indonesia, Philippines, Vietnam, Sri Lanka, Thailand, Egypt, Malaysia, Nigeria, and Bangladesh. These countries account for 60% of the global mismanaged plastic waste. Plastic trash has become so ubiquitous that it has prompted efforts to write a global treaty negotiated by the United Nations. Plastic pollution harms animals and possibly human health, as plastics contain additives that can leach out into the environment. Plastics also break down into micro plastics and nanofibers, which are ingested by aquatic and terrestrial organisms and may accumulate in food chains.

<sup>7</sup> I. Kottasová, 'The Great Pacific Garbage Patch is Now So Huge and Permanent that a Coastal Ecosystem is Thriving on It, Scientists Say | Cnn' [website] (2023), Cnn, < <https://edition.cnn.com/2023/04/17/world/plastic-pollution-ocean-ecosystems-intl-climate/index.html> > .

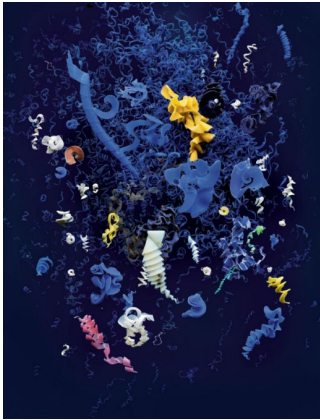


Figure 8: Shavings from various fabrication or drilling processes, source: <https://www.mandy-barker.com/commissions>



Figure 7: Printer cartridges have been washing up on European beaches since early 2014, after they spilled off a ship during an Atlantic storm, source: <https://www.mandy-barker.com/commissions>



Figure 9: Every piece of plastic here was found in the stomach of a single albatross chick. Laid bare outside the bird they killed, the plastic pieces—from the bottle caps in the top row to the tiny fragments along the bottom—all represent “parts of something” <https://www.mandy-barker.com/commissions>

Management and recycling of plastic waste: According to Geyer, Jambeck, and Law (2017), only 9% of plastic waste is recycled, 12% is burned, and 79% is disposed of in landfills and natural environments. Many scientists and conservationists believe that stopping plastic waste from ever entering rivers and seas is the best way to combat plastic pollution. Better recycling and waste management practices, better product design that considers the short shelf life of disposable packaging, and a decrease in the production of needless single-use plastics could all help achieve this. Approximately 11% of all solid waste materials are composed of plastic waste annually. Recycling rates vary widely by country and region, from a high of 60 percent in Europe to a low of 4 percent in Africa. Recycling plastics can save energy and natural resources, but it also faces many challenges, such as low quality, high costs, and limited markets.



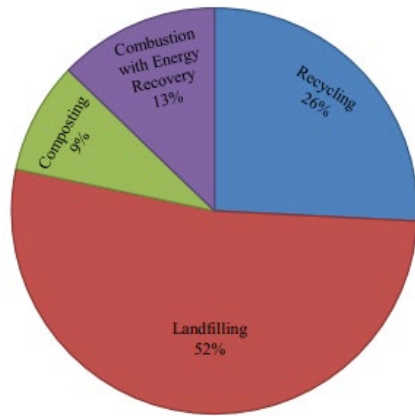


Figure 11: The following are the proposed targets to be achieved by 2030 in Kenya: - KPP



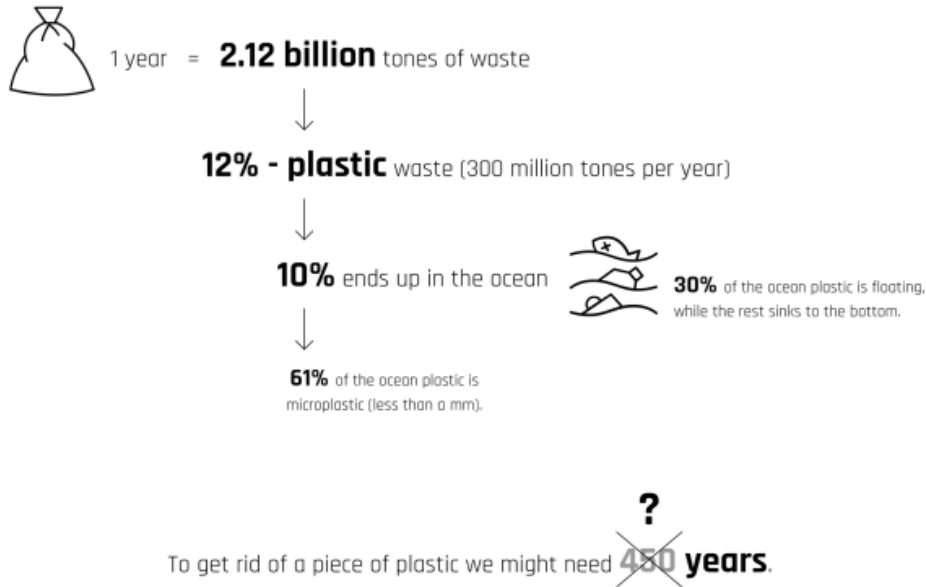
**Africa and Kenya’s plastic situation and solutions:** Africa is the second-largest continent in terms of population and land area, but it only produces 4.4% of the global plastic waste. However, it also has the lowest recycling rate of 9%, and the highest share of mismanaged plastic waste of 56%. Kenya is one of the African countries that has taken a strong stance against plastic pollution, by banning single-use plastic bags in 2017 and single-use plastic items in protected areas in 2020. It has also supported innovative initiatives to transform plastic waste into sustainable and affordable building materials<sup>8</sup>.

**Plastic waste as a building material:** One of the potential ways to use plastic waste is to convert it into a building material. Plastic waste can be melted, molded, or mixed with other materials to create bricks, tiles, panels, blocks, and other construction products. Some of the benefits of using plastic waste as a building material are that it is durable, lightweight, water-resistant, fire-resistant, and low-cost. Some of the challenges are that it may release toxic gases when heated, it may not meet the standards and regulations of the construction industry, and it may not be aesthetically pleasing or culturally acceptable<sup>9</sup>.

<sup>8</sup> R. Geyer, J. R. Jambeck, and K. L. Law, 'Production, Use, and Fate of All Plastics Ever Made', *Science Advances*, 3/7 (published online 2017), < <https://doi.org/10.1126/sciadv.1700782> > .

<sup>9</sup> . Mola et al, 'Recycling of Plastic Waste in to Construction Material' [website] (2020), < <https://www.grin.com/document/512889> > .

## 1.2: PROBLEM STATEMENT



Plastic waste is a global environmental and social challenge that requires innovative and sustainable solutions. The packaging sector holds the record for the greatest use of plastic, immediately followed by the built environment. The packaging industry uses the most plastic, with the construction sector being the next highest user<sup>10</sup>. This environmental crisis underscores society's duty to properly dispose of ever-increasing plastic waste. In construction alone, plastic is ubiquitous - in building materials like insulation, piping, and frames, as well as material storage, packaging, and transport. As leading stakeholders in the building sector, architects carry the weighty responsibility of curtailing plastic use while pioneering creative plastic reuse strategies. Through both professional leadership and personal example, architects must advance solutions to this environmental

threat. One of the potential solutions is to use plastic waste as a building material, especially in developing countries where there is lack of proper and sustainable waste management strategy. However, there are also opportunities and limitations associated with this approach, such as technical, economic, social, and environmental factors. The aim of this thesis is to explore the feasibility and potential of building from plastic waste in Kenya, a country that faces plastic waste crisis, and to identify the best practices and recommendations for its implementation<sup>11</sup>.

<sup>10</sup> N. Evode et al, 'Plastic Waste and Its Management Strategies for Environmental Sustainability', *Case Studies in Chemical and Environmental Engineering*, 4 (published online 2021), < <https://doi.org/10.1016/j.cscee.2021.100142> > , 100142.

<sup>11</sup> J. Hopewell, R. Dvorak, and E. Kosior, 'Plastics Recycling: Challenges and Opportunities', *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364/1526 (published online 2009), < <https://doi.org/10.1098/rstb.2008.0311> > , 2115-2126.

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### 1.3: RESEARCH AIM AND OBJECTIVES

This thesis aims to explore the feasibility and potential of building from plastic waste in Kenya, a country that faces the plastic waste crisis, and to identify the best practices and recommendations for its implementation. The main research question is: How can plastic waste be used as a building material in Kenya, and what are the opportunities and limitations of this approach? The specific objectives are:

1. To review the history, production, consumption, and impacts of plastics, the current plastic waste management and recycling practices, the existing and emerging technologies and initiatives for building from plastic waste, and the opportunities and limitations of this approach.
2. To analyze the technical, economic, social and environmental aspects of selected projects and initiatives that use plastic waste as a building material in Kenya and other similar contexts, comparison with conventional building materials
3. To understand the perspectives, experiences, and expectations of key stakeholders, such as policy makers, practitioners, researchers, and communities, involved or interested in building from plastic waste in Kenya as well as to assess the preferences, attitudes and perceptions of potential users and beneficiaries of plastic waste buildings in Kenya.

### 1.4: RESEARCH QUESTIONS

1. What are the main trends, challenges, and solutions related to plastic waste and its use as a building material in the global and local contexts?
2. How are plastic waste building materials and products designed, produced, and implemented in different types of buildings and structures, and what are their advantages and disadvantages compared to conventional building materials and products?
3. What are the motivations, challenges, and opportunities for building from plastic waste in Kenya, and what are the factors that influence the adoption and acceptance of this approach among different stakeholders and potential users and beneficiaries of plastic waste buildings in Kenya? What are their needs, preferences, and perceptions?

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## 1.5: SCOPE AND LIMITATIONS

**Geographical scope:** This study focuses on the context of Kenya, where plastic waste is a major environmental and social problem. The study also draws precedents and case studies from other African countries and the world, where similar initiatives and projects have been implemented or proposed using recycled waste materials in building construction.

**Theoretical scope:** This study is based on the theoretical framework of sustainable development, which aims to balance the environmental, economic and social dimensions of human activities. The study also adopts the concept of circular economy, which promotes the reduction, reuse and recycling of resources and waste. The study also applies the principles of sustainable architecture, which seeks to minimize the negative impacts and maximize the positive impacts of buildings on the environment and the society.

One of the **limitations** is the novelty of the concept of using plastic waste as a construction material in Kenya. This means that there is a lack of documentation, data and evidence on the feasibility, performance and impact of this approach in the local context. This may limit the validity and reliability of the findings and conclusions of this thesis. Another limitation is the challenge of venturing into a new industry that is not well established or regulated in Kenya. This may pose difficulties for the quality control, safety, legal and ethical aspects of the production, use and disposal of the plastic waste-based construction material.

## 1.6: ASSUMPTION OF STUDY

This study assumes that plastic waste is a valuable resource that can be reused as a building material for various applications in the construction industry. It also assumes that plastic waste-based construction material can provide social, economic and environmental benefits for communities. Furthermore, this study assumes that the production of plastic waste-based construction material can be done using low-cost and low-tech methods that are accessible and affordable for the target population in Kenya and other developing countries.

## 1.7: JUSTIFICATION OF THE STUDY

**Plastic waste as a sustainable resource:** This study aims to review the potential of using plastic waste as a construction material for various applications, such as bricks and tiles. Plastic waste is a global environmental problem that poses serious threats to human health, wildlife and ecosystems. In Kenya, plastic waste generation is estimated to be 600 tons per day, with only 10% being recycled or reused. The rest ends up in

landfills, dumpsites, water bodies or is burned, causing air, water and soil pollution<sup>12</sup>. Therefore, finding alternative ways to utilize plastic waste is crucial for achieving sustainable development goals and mitigating climate change impacts.

**Benefits of plastic waste-based construction material:** This study also explores the benefits of using plastic waste as a constituent of construction material, such as reducing the demand for natural resources, enhancing the strength and durability of the products, improving the thermal and sound insulation properties, and lowering the cost and carbon footprint of construction. Plastic waste-based construction material can also create employment opportunities and income generation for the informal sector, which is involved in collecting, sorting and processing plastic waste. Moreover, plastic waste-based construction material can promote circular economy and waste management practices, which are essential for enhancing environmental quality and public health.

**Challenges and research gaps:** This study also aims to identify the challenges and research gaps that need to be addressed for the commercialization and adoption of plastic waste-based construction material in Kenya and other developing countries.

### 1.8: SIGNIFICANCE OF THE STUDY

This study is significant because it relates to the ongoing global efforts to address the plastic pollution crisis, which is one of the main topics of the third session of the Intergovernmental Negotiating Committee on Plastic Pollution (INC-3) that took place in Nairobi, Kenya from 13 to 19 November 2023. The INC-3 aims to develop an international legally binding instrument on plastic pollution, based on a comprehensive approach that covers the full life cycle of plastic, from production to disposal. The study provides valuable insights and examples of how plastic waste can be reused and recycled as a construction material, which could contribute to the objectives and principles of the proposed instrument. The study also demonstrates the benefits of using plastic waste as a construction material, such as reducing the environmental and social impacts of plastic waste, promoting the concept of circular economy and waste management, and enhancing the performance and durability of various applications, such as bricks. Therefore, this study is of great relevance and importance for the academic community, the industry, the policy makers, and the society at large.

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<sup>12</sup> W. B. Group, 'Battling Kenya's Plastic Waste: Young Kenyan Woman is Transforming Waste into Sustainable and Affordable Building Materials' [website] (2021), World Bank Group, < <https://www.worldbank.org/en/news/feature/2021/03/11/battling-kenya-plastic-waste-young-kenyan-woman-transforming-waste-into-sustainable-and-affordable-building-materials> > .

## 1.9: STRUCTURE OF THE THESIS

**Chapter 1: Introduction.** This chapter provides the background, problem statement, research objectives, research questions, significance, assumption, scope and limitation of the study. It also introduces the main concepts and terms used in the study, such as plastic waste, construction material, circular economy, waste management, etc. It also gives an overview of the organization of the study.

**Chapter 2: Literature Review.** This chapter reviews the existing literature on the topic of using plastic waste as a construction material for various applications, such as bricks, tiles. It covers the types, properties, performance, and impact of plastic waste-based construction material. It also identifies the benefits and challenges, the opportunities and limitations, and the best practices and examples of using plastic waste as a construction material. It also identifies the research gaps and the need for the study.

**Chapter 3: Precedent Studies:** involves analyzing and learning from existing cases or situations that are relevant. This will enable the paper to Identify best practices, common pitfalls, and potential solutions for the research problem or question, Compare and contrast different approaches, methods, or outcomes of similar or related studies, demonstrate knowledge and understanding of the existing literature and the context of the research, Provide a rationale and justification for the research design, methodology, and analysis.

**Chapter 4: Research Methodology.** This chapter describes the research design, data collection methods, data analysis methods, and ethical considerations of the study. It explains the rationale and justification for choosing a mixed-methods approach, which combines quantitative and qualitative data. It also details the instruments, procedures, and techniques used for data collection and analysis, such as surveys, interviews, observations, and content analysis. It also discusses the validity, reliability, and limitations of the methods and the data.

**Chapter 5: Findings and Analysis.** This chapter presents the findings of the data analysis, and answers the research questions of the study. It uses tables, charts, graphs, and diagrams to illustrate the quantitative and experimental results, such as the technical properties of plastic waste as a construction material. It also uses quotes, themes, and narratives to describe the qualitative results, such as the perceptions, opinions, and experiences of the users and the designers regarding using plastic waste as a construction material.

**Chapter 6: Discussion of findings, Conclusion and Recommendations.** This chapter discusses the results of the data analysis, and compares and contrasts them with the literature review. It highlights the similarities and differences, the strengths and weaknesses, and the implications and recommendations of the findings. It also reflects on the limitations and challenges of the study, and suggests ways to overcome them. It also proposes a design solution that integrates plastic waste as a construction material into the urban fabric, and illustrates it with architectural drawings and

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renderings. This chapter summarizes the main findings, conclusions and contributions of the study, and provides recommendations for future research and practice. It also proposes a framework for using plastic waste as a construction material, based on the principles of circular economy and waste management. It also showcases some of the potential applications and benefits of using plastic waste as a construction material for various sectors and stakeholders.

### 1.10: DEFINITION OF OPERATIONAL TERMS

**Plastic:** A synthetic or semi-synthetic material that can be molded into various shapes and forms. Plastic is composed of polymers, which are long chains of repeating units called monomers. Plastic can be derived from natural or fossil sources, such as oil, gas, coal, cellulose, starch, etc.

**Plastic waste:** Any plastic material that is discarded, rejected or regarded as worthless by the original user or producer.

**Construction material:** Any material that is used for the construction of buildings, structures or infrastructure.

**Plastic waste-based construction material:** Any construction material that is made from plastic waste as a constituent or a modifier.

**Circular economy:** A system that aims to eliminate waste and the continual use of resources. Circular systems employ reuse, sharing, repair, refurbishment, remanufacturing and recycling to create a closed-loop system, minimizing the use of resource inputs and the creation of waste, pollution and carbon emissions.

**Sustainable waste management:** A process of handling waste materials in a way that minimizes the environmental impacts and maximizes the social and economic benefits. Sustainable waste management follows the waste hierarchy, which prioritizes waste prevention, reduction, reuse, recycling, recovery and disposal as the last resort.

**SDGs:** The Sustainable Development Goals, also known as the Global Goals, are a collection of 17 interlinked goals designed to be a “blueprint to achieve a better and more sustainable future for all”. The SDGs were set in 2015 by the United Nations General Assembly and are intended to be achieved by the year 2030.

**Plastic treaty:** A proposed international legally binding instrument on plastic pollution, which is currently being negotiated by the Intergovernmental Negotiating Committee on Plastic Pollution (INC-3). The plastic treaty aims to address the global plastic crisis by adopting a comprehensive approach that covers the full life cycle of plastic, from production to disposal, and by setting common targets, standards, obligations and mechanisms for cooperation and compliance.

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**Upcycling:** A process of transforming waste materials or unwanted products into new materials or products of higher quality or value. Upcycling adds value to waste by enhancing its functionality, aesthetics, durability or performance.

**Reuse:** A process of using waste materials or products again for the same or a different purpose, without significantly altering their physical form. Reuse extends the useful life of waste by reducing the need for new materials or products.

**Recycling:** A process of converting waste materials into new materials or products, usually of the same or lower quality or value. Recycling reduces the amount of waste that goes to landfills or incinerators, and conserves natural resources and energy.

**EMCA:** The Environmental Management and Co-ordination Act, which is the principal legislation in Kenya that provides for the establishment of an appropriate legal and institutional framework for the management of the environment and for matters connected therewith and incidental thereto.

**EPR:** Extended Producer Responsibility, which is a policy approach that holds producers responsible for the environmental impacts of their products throughout their life cycle, including upstream impacts from the extraction of raw materials, and downstream impacts from the collection and treatment of end-of-life products. EPR aims to incentivize producers to design products that are easier to reuse, recycle and recover, and to share the costs and responsibilities of waste management with other stakeholders.

**CDW-**Construction Demolition Waste

**MSW-**Municipal Solid Waste comprises household waste, commercial waste, and institutional waste, as well as residues collected from street cleaning services, public areas and private sectors

**Regulation:** A rule or directive made and maintained by an authority that governs the behaviour or actions of individuals or organizations. Regulation can be used to achieve various objectives, such as protecting the environment, ensuring public health and safety, promoting fair competition, etc.

**Repurposing:** A process of adapting waste materials or products for a new or different use, usually by modifying their physical form or function. Repurposing gives waste a new purpose or value by creating new products or services from existing ones.



Figure 12: Plastic as wealth. Source Bing 2023

## CHAPTER 02: LITERATURE REVIEW

*This chapter reviews the existing literature on the history, production, consumption, impacts, and management of plastic waste, as well as the types, properties, performance, and impact of plastic waste-based construction material. It also identifies the benefits and challenges, the opportunities and limitations, and the best practices and examples of using plastic waste as a construction material. It also identifies the research gaps and the need for the study.*

## 2.1: PLASTIC WASTE: SOURCES, IMPACTS AND MANAGEMENT

Plastic is a material that can change its shape by definition. The word plastic comes from the Greek word "plastikos," which means "moldable." Plastics come in thousands of varieties. It may be organic or synthetic. Some of them are also referred to as polymers, which are big molecules made up of numerous subunits that repeat. It however, also poses a serious threat to the environment and human health due to its persistence, accumulation, and toxicity. In this section the paper provides a brief history of plastic production, as well as the sources, impacts, and management of plastic waste.

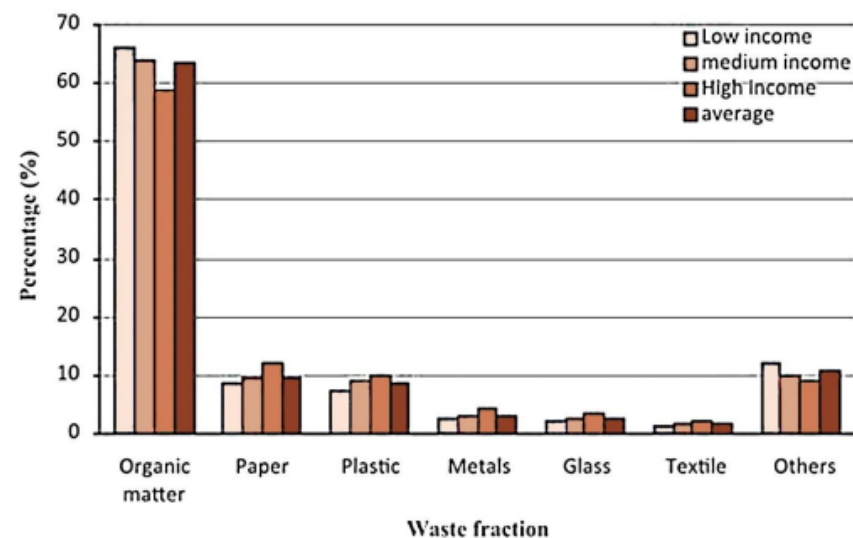


Fig 12: Average waste composition (percentages) for three socio-economic groups, source: Ogwueleka 2013

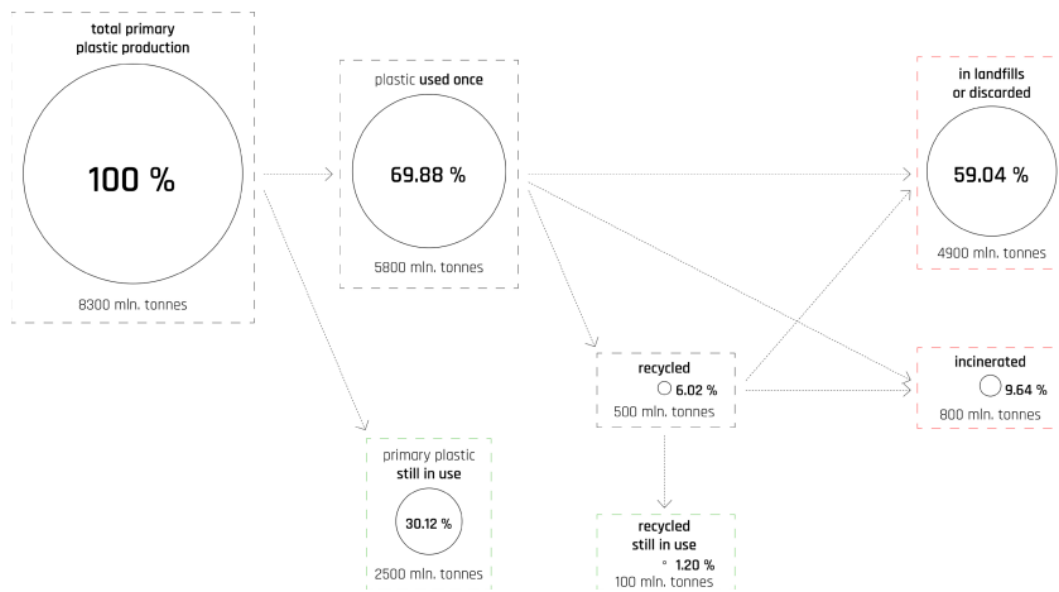


Figure 13 Fate of plastic waste. UNEP 2016

## 2.1.1: HISTORY OF PLASTIC PRODUCTION

### Natural source of plastic from the blue gum tree



Figure 14 Early use of plastic NATGEO ALBUM 2019

The **blue gum tree** scientifically known as *Eucalyptus globulus*, is an evergreen tree that has its origins in Australia. It is one of the most widely cultivated species of eucalyptus, and it is also known as the Tasmanian blue gum or the southern blue gum. The blue gum tree produces a resinous substance called kino, which is a type of natural plastic. Kino is a dark red or brown gum that exudes from the trunk and branches of the tree when they are wounded or cut. Kino is composed of tannins, sugars, and other organic compounds, and it has antiseptic and astringent properties. Kino was used by the indigenous people of Australia for medicinal purposes, such as

treating wounds, diarrhea, and dysentery. Kino was also used by the early settlers of Australia as a dye, ink, and varnish.

#### Natural plastic uses:

**As chewing gum:** The indigenous people of Australia chewed the kino gum to clean their teeth and freshen their breath. They also used the Kino gum to make balls, toys, and ornaments.

**As a precursor to synthetic plastic:** In the late 19th century, a German chemist named Adolf von Baeyer synthesized a polymer called polyacetylene from acetylene gas and zinc chloride. Polyacetylene was a rubber-like material that could be molded into various shapes and had electrical conductivity. However, polyacetylene was unstable and decomposed easily. Baeyer tried to improve the stability of polyacetylene by using kino gum as a starting material, but he was unsuccessful. Nevertheless, his experiments paved the way for the development of synthetic plastics in the 20th century.

**The first synthetic plastic:** In 1907, Leo Baekeland invented Bakelite, the first fully synthetic plastic, using phenol and formaldehyde. Bakelite was a good insulator and heat resistant, and it was suitable for mass production. Bakelite marked the beginning of the global plastics industry.

**The rise of plastic production:** The global plastic production increased rapidly after World War II, as plastics offered a cheap, versatile, and lightweight alternative to traditional materials such as metal, wood, and glass. Plastics were used for a wide range of applications, from packaging and consumer goods to aerospace and medical devices. By 2019, the annual production of plastics reached 460 million tons from 2.3 million tons and is expected to double by 2050 (1 trillion tons)<sup>13</sup>. *“If you spread all of this plastic equally, ankle-deep, it would cover an area the size of Argentina.” Roland Oeyer (an industrial ecology professor and the study’s lead author), 2017*

**The development of new plastics:** Throughout the 20th century, many new types of plastics were invented and improved, each with different properties and uses. Some of the most widely used plastics today are High Density Propylene (HDPE), polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS) and polyethylene terephthalate (PET). These plastics are made from synthetic polymers.



**The problem of plastic waste:** As plastic production grew, so did plastic waste. Plastic waste is generated from various sources, such as packaging, agriculture, construction, and electronics. While plastics have brought many benefits to society, they have also created many environmental problems. Plastics are mostly derived from fossil fuels, which contribute to greenhouse gas emissions and climate change. Plastics are also durable and resistant to degradation, which means they can persist in the environment for a long time and cause pollution, especially in the oceans. About 8 million tons of plastic waste enter the oceans every year, where it

breaks down into microplastics and affects marine life and ecosystems<sup>14</sup>. Plastic waste also accumulates on land, where it can leach harmful chemicals into the soil and water. Plastic waste poses a threat to human health, as it can contaminate food, water, and air with toxic substances.

<sup>13</sup> R. Geyer, J. R. Jambeck, and K. L. Law, 'Production, Use, and Fate of All Plastics Ever Made', *Science Advances*, 3/7 (published online 2017), < <https://doi.org/10.1126/sciadv.1700782> > .

<sup>14</sup> J. Hopewell, R. Dvorak, and E. Kosior, 'Plastics Recycling: Challenges and Opportunities', *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364/1526 (published online 2009), < <https://doi.org/10.1098/rstb.2008.0311> > , 2115-2126.

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## 2.1.2: SOURCES, IMPACTS, AND MANAGEMENT OF PLASTIC WASTE

**Sources of plastic waste:** Plastic waste is generated from both primary and secondary sources. Primary sources are the products that are intentionally designed to be used once or for a short time, such as plastic bags, bottles, straws, and cups. These are known as Single use plastics. Secondary sources are the products that are durable and have a longer lifespan, such as plastic furniture, toys, appliances, and vehicles. However, these products can become waste when they are discarded, lost, or abandoned.

**Recycled plastic sources** -Include CDW or MSW plastic, such as pipes, bottles, bags, or films. Recycled plastic can be reused in its original form for similar applications or shredded and melted into new products such as tiles, panels, or bricks. Recycled plastic can also be blended with other waste materials, such as wood, rubber, or textile, to create new types of plastic-based composites with enhanced properties or functionality.

**Impacts of plastic waste:** Plastic waste has negative impacts on the environment, wildlife, and human health. Plastic waste can degrade the natural beauty and quality of the environment, as well as reduce the economic value of tourism and fisheries. Plastic waste can harm wildlife, as animals can ingest, entangle, or suffocate from plastic debris. Plastic waste can also affect human health, as plastic can release toxic chemicals that can accumulate in the food chain and cause various diseases and disorders.



Figure 16: Dumpsite in Kenya-Remi 2018

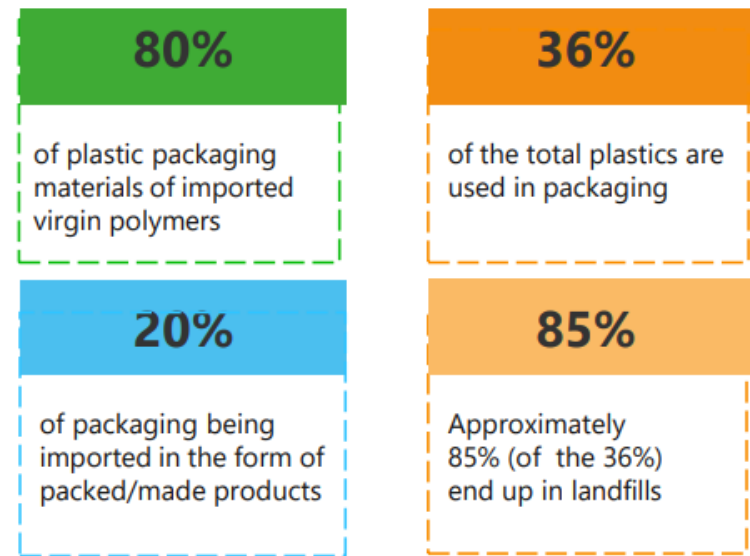


Figure 15: Statistics around plastic waste management in Kenya. Source KPP



Figure 17: Effects on Plastic pollution on ocean life,Source Natgeo 2023

**Management of plastic waste:** Plastic waste can be managed by various strategies, such as prevention, reduction, reuse, recycling, recovery, and disposal<sup>15</sup>. Prevention is the most effective and preferred strategy, as it aims to avoid the generation of plastic waste in the first place. Reduction is the strategy of minimizing the amount and toxicity of plastic waste. Reuse is the strategy of using plastic products more than once for the same or different purposes. Recycling is the strategy of converting plastic waste into new products or materials. Recovery is the strategy of extracting energy or materials from plastic waste. Disposal is the last resort strategy of getting rid of plastic waste in a safe and controlled manner.

The Kenya Plastics Pact report highlights that Kenya's 2022 Sustainable Waste Management Act does not clearly define "recyclable." Without a unified definition, claims of recyclability often fail to account for real-world factors like existing recycling infrastructure, market dynamics, and economic viability. The issue is simple - for plastic packaging to be truly recyclable, it must demonstrably be recycled in practice. Drawing on the Ellen MacArthur Foundation's Global Commitment, the Kenya Plastics Pact proposes this definition: **Plastic packaging qualifies as recyclable only if post-consumer collection, sorting, and recycling have been successfully implemented at scale**<sup>16</sup>.



Figure 18: Waste Management Process. Source: (Plastindia Foundation, 2019)

The following are Design guidelines for recyclability of plastic waste in Kenya.

1. The design guidelines are based on the compatibility of different materials, colors, closures, decorations, and additives with the current recycling infrastructure and market conditions in Kenya. The design guidelines are presented in three categories: green, yellow, and red, indicating the level of recyclability of each packaging feature<sup>17</sup>.

<sup>15</sup> United Nations Environment Programme, 'Africa Waste Management Outlook' [website] (2018), letc, < <https://www.unep.org/ietc/resources/publication/africa-waste-management-outlook> > .

<sup>16</sup> 'Kenya Plastics Pact', [website] (2022), < <https://kpp.or.ke/> > .

<sup>17</sup> <sup>3</sup>EllenMacArthur Foundation (2018). NewPlasticsEconomy Global Commitment, 25 October. [Ellenmacarthurfoundation.org:](https://www.ellenmacarthurfoundation.org/) <https://www.ellenmacarthurfoundation.org/assets/downloads/Global-Commitment-Documents-to-download-on-website-2.pdf>.

- **Green:** Packaging attributes compatible with the primary material that can be effectively separated and recycled at scale without contamination.
- **Yellow:** Packaging that may be recyclable in some applications but risks polluting recycling streams.
- **Red:** Packaging materials and components incompatible with mainstream recycling, inseparable, and contaminating to the recycling process.

Green	Yellow	Red
Green denotes packaging features that are generally compatible with or separable from the main material and is acceptable in recycling processes in large volumes.	Yellow denotes packaging materials that are recyclable in some applications, but could contaminate the recycling process.	Red denotes packaging items and materials that are generally not compatible with the current recycling systems or not separable from the main material in current processes and will contaminate the recycling process.

Figure 19: Plastic recyclability guidelines by KPP 2023

These design guidelines aim to offer definitive suggestions to stakeholders on optimizing plastic packaging for compatibility with available mechanical recycling facilities. They will be periodically revised to align with evolving collection methods, sorting technologies, recycling processes, and domestic infrastructure in Kenya. The goal is to provide decision-makers up-to-date, actionable best practices for creating recyclable packaging.

According to the KPP, PET and HDPE are two common types of plastic packaging that have different properties and recycling processes. PET is clear, strong, and lightweight, while HDPE is translucent, durable, and moisture-resistant. The design guidelines for recyclability are based on the compatibility of the packaging features with the current and projected mechanical recycling infrastructure in Kenya. The guidelines use a green-yellow-red rating system to indicate the level of compatibility.

The packaging features that affect recyclability include **material and material combination, barriers and coatings, closures, colour, decorations, and additives**. The guidelines provide specific recommendations for each feature and explain the rationale behind them.

The guidelines aim to help decision-makers design plastic packaging that is reusable or recyclable, and to reduce the amount of plastic packaging waste that ends up in landfills or the environment. The guidelines are aligned with the targets and vision of the Kenya Plastics Pact, which is an initiative to transform the plastics system into a circular economy.

The Reduce, Reuse and Recycle strategy principally targets plastic waste, as recycling has the greatest capacity to handle these materials. However, Kenya's recycling infrastructure remains inadequate for the volumes of plastic generated annually. Nonetheless, recycling represents the optimal solution environmentally and socioeconomically. It may offer the sole path for Kenya to resolve the plastic waste issue.

- i. Primary recycling: Reprocessing waste plastic from manufacturing rather than post-consumer sources. Though such industrial waste is modest compared to consumer plastic refuse, mandated recycling by industries is essential.
- ii. Secondary recycling: Recycling post-consumer plastics via sorting, shredding, rinsing and drying into reusable feedstock. With viable infrastructure from Abuja's government, or private recycler incentives, secondary recycling could significantly impact plastic waste levels<sup>18</sup>.
- iii. Tertiary recycling: Chemical treatment to depolymerize post-consumer plastic polymers into reusable monomers. Implementation difficulties from chemical/equipment costs rule this method out for smaller communities.
- iv. Quaternary recycling: Incinerating plastic waste for energy recovery. Though energy retrieval is possible, burning plastics emits greenhouse gases, damaging the environment. Hence incineration is a last resort.

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<sup>18</sup>H. Li. et al, 'Expanding Plastics Recycling Technologies: Chemical Aspects, Technology Status and Challenges' [website] (2022), ChemRxiv, <<https://chemrxiv.org/engage/chemrxiv/article-details/62575f70ebac3a262fd3e505> > .

The following tables below display the recyclability guidelines for PET and HDPE plastics<sup>19</sup>

ITEMS	GREEN	YELLOW	RED
MATERIAL & MATERIAL COMBINATION	- PET		- PVC - PS - Metal - Paper - Cardboard
BARRIERS AND COATINGS	- EVOH < 5%	- PA-MXD6 multilayer with <6wt%	- EVOH / PA >5% monolayer blends - PA-Polyamide multilayer with >6wt% - PVdc
CLOSURES	- Closures made of PP, HDPE or other materials with a density of less than 1 g/cm <sup>3</sup> . - Closure systems without liners.	- Ethylene-vinyl acetate (EVA) or Thermoplastic elastomers (TPE) liners	- Closures made of metal, aluminium-containing materials (with a layer thickness greater than 5 µm), PS, Acetal plastic, also called polyacetal and polyoxymethylene (POM) and PVC.
COLOUR	- Transparent clear and transparent light blue are fully recyclable.	- Other transparent colours	- Opaque colours
LABELS	- PE and PP labels	- Conventional paper labels. During the washing process of conventional paper labels, fibres come out that contaminate the recycle.	- Large-scale decorations covering more than 50% of the packaging surface can impair the sorting of the packaging. - Full body label. - PET as well as non-wet-strength paper labels can contaminate the PET fraction. - PS labels.
SLEEVES	- If sleeves are used, they should cover a maximum of 40% of the packaging and be made of a material (e.g. PP and PE) with a density of less than 1g/cm <sup>3</sup> to enable ease of separation in the sink float separation process.		- Sleeves made of a material with a density greater than 1 g/cm <sup>3</sup> (e.g., PVC, Oriented Polystyrene (OPS), Polylactic acid (PLA) should be avoided.
INKS	- Non-bleeding inks are preferable to avoid potential contamination.		- Bleeding inks.
ADHESIVES	- Cyanoacrylate adhesives, - UV curable adhesives as well as some epoxy and structural adhesives <sup>1</sup> .		- Adhesive materials containing metal or aluminium (with a layer thickness of greater than 5 microns µm) can lead to unwanted sorting into the metal fraction.
DIRECT PRINTING	- The batch coding and the indication of the best-before date should ideally be carried out in the form of an embossing or laser marking.	- The batch coding and indication of the best-before date done by means of minimal direct printing with other coding systems (e.g., ink-jet), provided that food-grade inks are used.	- Extensive direct printing on the packaging is disadvantageous, as released printing inks can impair the clarity of the recycle or contaminate the recycling stream via released printing inks in the wash water.

ITEM	GREEN	YELLOW	RED
MATERIAL AND MATERIAL COMBINATION	- Multi-layered HDPE, PP and PET.		- Multi-layered PLA, PVC and PS.
BARRIERS AND COATINGS	- EVOH barriers less or equal to 5% concentration. - Water-based coatings (Acrylic coatings, Polyurethane coatings, Epoxy coatings, UV-curable coatings).		- EVOH more than 5% concentration.
CLOSURES	Caps - HDPE.		- PVC. - PS. - PET.
	Seals - Form Seals. - Induction seals. - Pressure-sensitive. - Expanded Polyethylene (EPE).		- PVC. - PET.
	Liners - PE.		- PVC. - PET.
COLOUR	- Clear colours. - Green. - Blue. - Brown.		- Dark /Black colours.
DECORATIONS	Labels - PVOH (polyvinyl alcohol) labels or other water-soluble materials. - Thermal transfer printed labels. - Pressure-sensitive labels with removable adhesive.	- PP labels.	- PVC labels.
	Sleeves - Sleeves in PE & PP (all with density < 1 g/cm <sup>3</sup> ).	- Sleeves in PE, PLA, (all with density >1 g/cm <sup>3</sup> ).	- Aluminium sleeves. - Metallized sleeves. - PVC sleeves.
	Inks - Water-based inks. - Solvent-based inks. - UV-cured inks. - Non-bleeding inks.		- Oil-based inks. - Metallic inks. - Inks containing heavy metals such as lead, cadmium, and mercury. - Inks containing halogens such as chlorine and bromine. - Inks that bleed.
	Adhesives - Water soluble and water releasable adhesives.		- Pressure-sensitive adhesives. - Rubber-based adhesives. - Polyvinyl chloride (PVC) based adhesives.
Direct Printing	- Production or best-before date.		- Any other direct printing.
ADDITIVES	- UV Stabilizers.	- Calcium Carbonate (CaCO <sub>3</sub> ).	

Figure 20: PET and HDPE plastics recyclability guidelines

<sup>19</sup> Silva SM, Medeiros ES, Galvão LS, Santos ASF Characterization of adhesive content in post-consumer poly (ethylene terephthalate) bottles and assessment of its impact on poly (ethylene terephthalate) recyclability Progress in Rubber, Plastics and Recycling Technology 2023 0 0 doi 10.1177/14777606231152507

## 2.2: WORLD VIEW OF LITERATURE

### OVERVIEW

Current research on constructing with plastic waste is polarized. Raut (2015) and Gupta (2023) spotlight potential benefits like cost and sustainability. However, Cirino (2023) raises concerns over ecological harm. Silva (2021) advocates life cycle assessments to enhance long-term sustainability. Collectively these indicate a need to address knowledge gaps around plastics reuse impacts and solutions.

Puttaraj et al. found reused bottles substantially conserve embodied energy versus bricks while lowering cement emissions. Such "green" projects have captured industry attention. Typically, bioclimatic, bottle houses remain warm and cool respectively. Constructing walls, ceilings and columns from bottles cuts costs 45%, especially utilizing local labor for 75% savings over bricks<sup>20</sup>.

Mansour and Ali (2015) achieved affordable, comfortable housing via bottle insulation superior to conventional materials. Though unrecyclable, repurposing plastic bottles waste while aiding India's poor<sup>21</sup>.

Puttaraj et al. examined efficient plastic-soil brick fabrication resolving disposal and litter issues. Plastics require centuries to decompose, so reuse mitigates environmental harm. Bottles could replace traditional building supplies.

Kumar found plastic bottle walls cheaper and stronger than bricks. With slow degradation, unchecked plastic bottle proliferation causes pollution<sup>22</sup>.

Ahmed noted shifting perceptions towards construction applications like load-bearing walls and intuitive vaults using bottles. Further research into utilizing plastic structurally is warranted alongside policy changes<sup>23</sup>.

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<sup>20</sup> Puttaraj M. H. et al, 'Utilization of Waste Plastic In Manufacturing Of Plastic-Soil Bricks' (2018), < [https://www.researchgate.net/publication/329707682\\_Utilization\\_Of\\_Waste\\_Plastic\\_In\\_Manufacturing\\_Of\\_Plastic-Soil\\_Bricks](https://www.researchgate.net/publication/329707682_Utilization_Of_Waste_Plastic_In_Manufacturing_Of_Plastic-Soil_Bricks) >.

<sup>21</sup> A. M. H. Mansour, and S. A. Ali, 'Reusing Waste Plastic Bottles as an Alternative Sustainable Building Material', *Energy for Sustainable Development*, 24 (published online 2015), < <https://doi.org/10.1016/j.esd.2014.11.001> >, 79-85.

<sup>22</sup> S. Kumar, 'Utilization of Plastic Waste in Construction of Roads' [website] (n.d.), < [https://www.academia.edu/28788046/Utilization\\_of\\_Plastic\\_Waste\\_in\\_Construction\\_of\\_Roads](https://www.academia.edu/28788046/Utilization_of_Plastic_Waste_in_Construction_of_Roads) >.

<sup>23</sup> N. Ahmed, 'Utilizing Plastic Waste in the Building and Construction Industry: A Pathway Towards the Circular Economy', *Construction and Building Materials*, 383 (published online 2023), < <https://doi.org/10.1016/j.conbuildmat.2023.131311> >, 131311.

Vishal et al. found ecobricks, as controlled, compacted plastic, suitable for various builds. Relatively strong and lightweight, their strength rivals concrete<sup>24</sup>.

Odulele et al. built walls and pillars from bottle "bricks." Various configurations were tested for strength and fracture patterns. Sand-filled bottles bear 4.3 N/mm<sup>2</sup> though plaster bears more load. Using local materials, these earthquake-resilient houses are inexpensive.<sup>25</sup>.

## LITERATURE ON THE TOPIC

Authors & Publication	Topics of the articles	Objective	Types of Citations	Methods	Findings	Future Research
Hopewell et al. (2009)	Plastics Recycling	To review the current state and future potential of plastics recycling	Philosophical Transactions of the Royal Society A	Literature review	Plastics recycling is influenced by technical, economic, and social factors, and can offer environmental and economic benefits	Identify key challenges and opportunities for plastics recycling
Ragaert et al. (2017)	Mechanical and Chemical Recycling of Plastics	To compare and contrast the advantages and disadvantages of mechanical and chemical recycling of plastics	Polymer Degradation and Stability	Literature review	Mechanical recycling is more widely used and less energy-intensive, but has limitations in quality and applicability. Chemical recycling is more versatile and	Highlight the need for a combination of recycling methods and a life cycle assessment approach

<sup>24</sup> Dr. Vishal P. et al, 'Development of Eco-Friendly Bricks for Sustainable Construction' [website] (2022), < <https://iopscience.iop.org/article/10.1088/1757-899X/1248/1/012109/meta> > .

<sup>25</sup> Oludele M. S, Awobona S., and Omodehin O. A, 'Knowledge and practice of recycled plastic bottles (RPB) built homes for sustainable community-based housing projects in Nigeria' [website] (2020), < <https://www.tandfonline.com/doi/full/10.1080/23311886.2020.1778914> > .

					can produce higher quality products, but has higher costs and environmental impacts	
Nathan, Kumar, & Shah (2018)	Utilization of Plastic Waste in Construction	To create awareness and commitment to recycle plastic waste	Journalistic	Descriptive	The future of plastic waste management lies in the collaboration of various stakeholders and the adoption of innovative technologies	
Authors & Publication	Topics of the articles	Objective	Types of Citations	Methods	Findings	Future Research
Rios et al. (2017)	Plastic Pollution in the Marine Environment	To assess the sources, impacts, and solutions of plastic pollution in the oceans	Review	Analytical	Plastic pollution poses serious threats to marine ecosystems and human health, and requires urgent actions from global to local scales	
Wang et al. (2016)	Plastic Waste Pyrolysis	To investigate the feasibility and efficiency of converting plastic waste into	Experimental	Quantitative	Plastic waste pyrolysis can produce high-quality fuel oil with high yield and low cost, and can also reduce	

		fuel oil by pyrolysis			greenhouse gas emissions and energy consumption	
Velis (2014)	Global Recycling Markets	To examine the current trends and challenges of global recycling markets, especially for plastic waste	Report	Qualitative	Global recycling markets are dynamic and complex, and are influenced by various factors, such as policies, regulations, trade, prices, quality, and demand	
Authors & Publication	Topics of the articles	Objective	Types of Citations	Methods	Findings	Future Research
Jambeck et al. (2015)	Plastic Waste Inputs from Land into the Ocean	To estimate the amount and sources of plastic waste that enters the ocean from land-based activities	Modeling	Statistical	About 8 million metric tons of plastic waste enter the ocean every year, and this amount is expected to increase by an order of magnitude by 2025	
Song et al. (2009)	Biodegradable and Compostable Alternatives to Conventional Plastics	To evaluate the potential and limitations of biodegradable and compostable plastics as	Review	Comparative	Biodegradable and compostable plastics have some advantages over conventional plastics, such as	

		alternatives to conventional plastics			reducing landfill waste and greenhouse gas emissions, but they also have some drawbacks, such as higher cost and lower performance	
Andrady & Neal (2009)	Applications and Societal Benefits of Plastics	To highlight the applications and societal benefits of plastics in various sectors and domains	Review	Evaluative	Plastics have contributed to the improvement of human health, safety, comfort, and convenience, as well as to the development of science, technology, and innovation	
Barnes et al. (2009)	Accumulation and Fragmentation of Plastic Debris in Global Environments	To document the occurrence and effects of plastic debris in different environmental compartments	Review	Synthesis	Plastic debris has accumulated in various environments, such as terrestrial, freshwater, coastal, and marine, and has fragmented into smaller pieces, posing risks to wildlife and humans	

## 2.3: PLASTIC WASTE AS A BUILDING MATERIAL: TYPES, PROPERTIES AND APPLICATIONS

### 2.3.1: TYPES OF PLASTIC WASTE

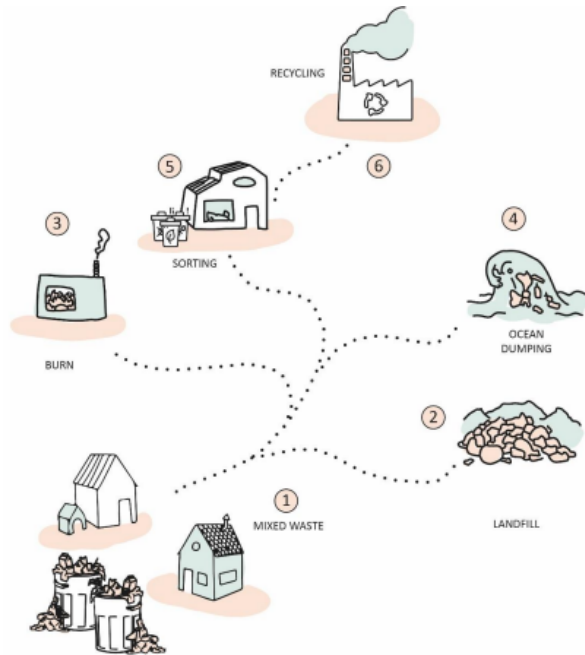


Figure 21 Flow of plastic Maimuna Shehu 2019

Plastic's versatility makes it a component of most modern products, with numerous construction applications owing to its useful properties. Plastics serve in the industry for insulation, piping, fixtures, and roofing, leveraging qualities like chemical resistance, ductility, stability and flame retardation. Their moldability allows uses in electrical insulation and decorative wall finishes, while added pigments can visually enhance buildings<sup>26</sup>. Common plastic varieties used in construction include as shown in the Figure 21 below. Plastics' moldability enables varied construction applications. Combined with durability, hardness and impenetrability, this plasticity facilitates diverse building roles through simple processing like injection molding or extrusion. Such customizability sees ongoing architectural innovation.

Plastics carry a numbered 1-7 label denoting their resin types, critical for recycling. The first six comprise over 90% of all plastics: polyethylene (type 2 - HDPE and type 4 - LDPE) at 36%, polypropylene (type 5 PP) at 21%, polyvinyl chloride (type 3 - PVC) at 12%, and polyethylene terephthalate (type 1 - PET).

Type 7 denotes "other" plastics, encompassing almost a thousand miscellaneous resins. Without further specifics, #7 plastics cannot be effectively recycled without environmental risk. For comparison, a common organic plastic, polylactic acid, was added to the synthetic plastic resins listed.

Among market plastics, only thermoplastics like PET, HDPE, LDPE, PVC, PP and PS allow recycling per Environmental Science and Pollution Research. "Plastic Architecture" focuses on



Figure 22: Thermoplastic categorization  
(<https://community.preciousplastic.com/academy/plastic/basics>)

<sup>26</sup> V. Gupta, and Sinha A, 'Application of plastic wastes as construction material for sustainable development: A review' [website] (2023), <<https://wjaets.com/sites/default/files/WJAETS-2023-0059.pdf>> .

PET, HDPE, PP and bioplastic PLA - selectively nontoxic, common in single-use packaging, and environmentally threatening from short usage lifetimes. Together PE, PP and PET comprise 42% of non-fibrous plastics, though PET's prevalence in bottles and cartons drives special attention for recycling and reuse. With toxicity concerns around many plastics, these common thermoplastics offer safer reuse potential across construction applications. As recycling processes and infrastructure develop, their popularity provides both supply and impetus for innovation.

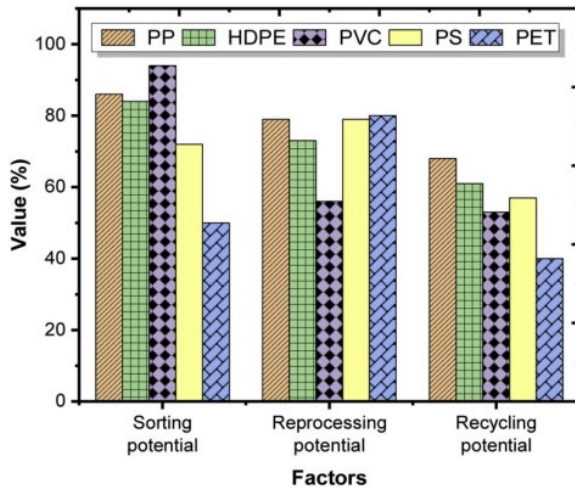


Figure 23: Recycling potential of the various types of plastics

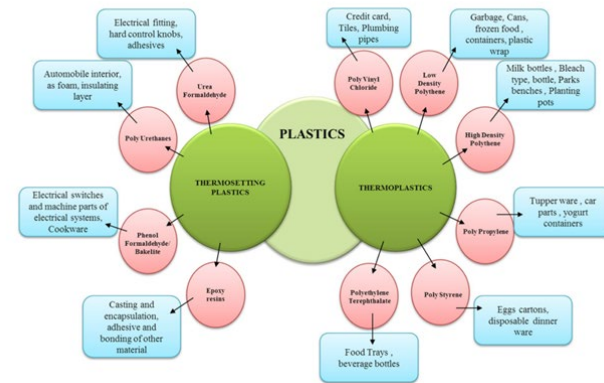


Figure 24: Classification of different types of plastics and suitable applications: Environmental Science and Pollution Research 2022

The non-recyclable plastic is under the category of **thermosetting plastics and synthetic fibers**, e.g., multilayer and laminated plastic, Teflon, PUF (polyurethane foam), Bakelite, polycarbonate, melamine and nylon. Figure below shows the classification of different plastics and their suitable applications.

Based on particle size, plastics are classified as:

- Nano plastics: particle size < 0.0001 mm
- Small microplastics: particle size 0.00001–1 mm
- Large microplastics: particle size 1–4.75 mm

- Meso-plastics: particle size 4.76–200 mm
- Macro plastics: particle size >200 mm

Plastics comprise thermoplastics and thermosets. Thermosets' irreversibly bonded polymers permanently retain shape after molding, preventing recycling. Thermoplastics repeatedly soften and harden with temperature shifts, enabling reuse. Fortunately, ~80% of global plastic waste is recyclable thermoplastic.

Further thermoplastic subgroups exist based on properties and structure. Their resin type is typically imprinted on products as a numbered plastic code or name. As most waste is recyclable thermoplastic, improved processing infrastructure and innovation may resolve environmental issues around plastic. However, designing for recyclability and minimizing plastic usage altogether remain imperative across industries utilizing this persistently problematic materials.

### 2.3.2: APPLICATIONS OF PLASTIC WASTE CONSTRUCTION MATERIAL OVERVIEW



Figure 25 Stages for application in building materials. Source Plastindia 2020

Plastic is one of the most widely used materials in the world, with a global production of about 359 million tons in 2018. However, plastic also poses a serious environmental problem, as only 9% of the plastic waste generated is recycled, while the rest ends up in landfills or oceans, causing pollution, greenhouse gas emissions and harm to wildlife. Plastic bottles, especially those made of polyethylene terephthalate (PET), are among the most common types of plastic waste, with a global consumption of about 500 billion units per year. Therefore, finding ways to reduce, reuse and recycle plastic bottles is a crucial challenge for society and designers.

Repurposing plastic bottles for construction presents another recycling pathway within a circular economy. Designers have long explored such building applications, devising methods centered on reusing this ubiquitous waste. Abundant and inexpensive, bottles could significantly supplement materials, notably for self-builds. This research examines their structural potential through a technique leveraging bottles as load-bearing components.

Studies by Awoyera and Adesina indicate plastic types and properties inform recycling possibilities. The hardness and rigidity of high-density polyethylene (HDPE) suits plastic lumber and furniture. Flexible low-density polyethylene (LDPE) can produce bricks and blocks. Hard yet flexible polypropylene (PP) serves well as asphalt aggregate. Hard, brittle polystyrene (PS) suffices for low-stress insulation roles. Much like HDPE, rigid polyvinyl chloride's (PVC) properties align with cement-based materials use. Finally, the strength and moldability of polyethylene terephthalate (PET) make it an ideal fiber reinforcement in cement.

Repurposing plastics to reduce waste first requires understanding characteristics governing applications. This enables matching types to optimal construction uses, improving recycling efficiency. Further research and infrastructure growth could unlock the full structural potential of disposed plastic.

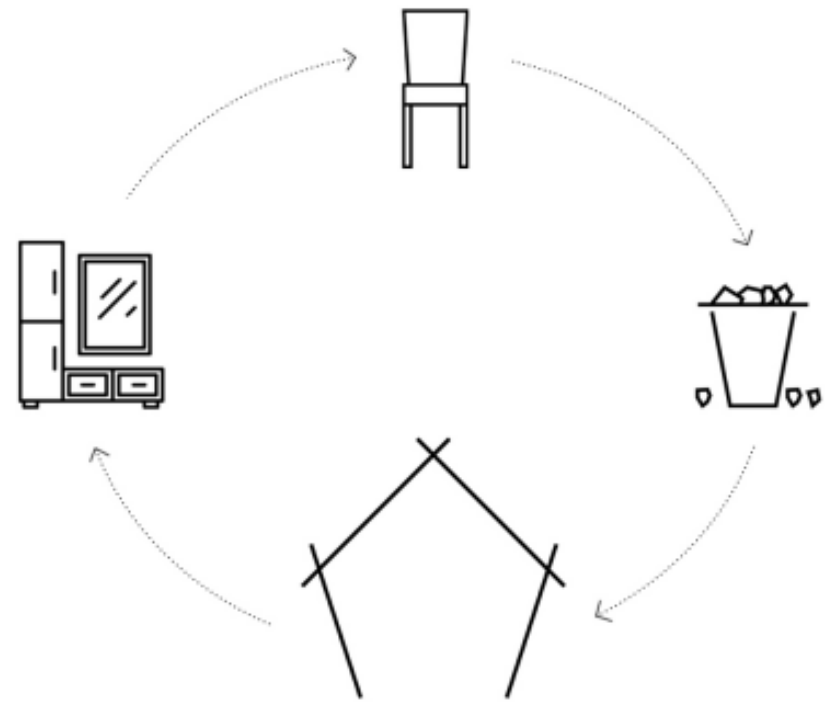


Figure 26 Circular economy flow Source Plastindia 2021

No.	Plastic Material	Uses	Form in which it is commonly used	Normal colour
1	Expanded polystyrene	Thermal insulation	Thin sheets in slabs 12mm thick	White
2	Expanded polyvinyl chloride (PVC)	Thermal insulation	Boards 20 to 50 mm thick	Yellow brown
3	Foamed urea formaldehyde	Thermal insulation	Foamed in situ	White
4	Foamed phenol formaldehyde	Thermal insulation	Sheets and blocks	Deep red
5	Foamed polyurethane	Thermal insulation	Sheets and blocks or foamed in situ	Brown
6	Expanded ebonite	Thermal insulation	Sheets	Brown or black
7	Polythene	Damp-proofing, plumbing	Thin sheets, pipes, cisterns	Transparent to black
8	Polypropylene	Domestic drainage, but water overflow tanks		
9	Unplasticised PVC	Rainwater goods, ventilation, ducts, pipes of water mains		
10	Acrylic resins	Sinks and baths		Various
11	Nylon	Cold water fittings, window furniture		Various
12	Phenolic resins	Adhesives for laminates		Dark
13	Melamine	Laminates	Sheets	Many

Figure 27: Uses of plastic in the construction industry currently

The review concludes that the proposed method is a viable and innovative way of reusing plastic bottles for building purposes, as it offers a simple, cheap and environmentally friendly solution, especially in developing countries where the scarcity of resources and the abundance of plastic waste are critical issues. It also suggests that the method can be applied to different types of buildings, with different appearances and functions, depending on the design choices and the availability of materials. The research also acknowledges that the method is not a substitute for other recycling hypotheses, but rather an additional circuit that can contribute to the reduction of plastic waste and the improvement of living conditions.

Plastics currently feature in buildings primarily as coverings, panels, sheets, foams and pipes. However, their properties could augment conventional building materials for enhanced functioning, lifespan and affordability per The Constructor (2019). Plastic even reinforces concrete today in some applications. Moreover, architects internationally utilize plastic for affordable, sustainable housing in developing regions.

With further research and infrastructure supporting repurposing, plastic waste could transform into structural components matching or exceeding traditional counterparts in strength, insulation, customizability and beyond. In a circular economic model focused on renewal, reused plastics present abundant possibilities across the

building and construction spectrum - from major materials to minor fittings. With responsible design and processing, these persistent wastes may protect rather than pollute environments far into the future.

### 2.3.2.1: CONSTRUCTION METHODOLOGY



Figure 28: Bottle school Guatemala-Source Plastindia 2023

#### Introduction

Andreas Froese pioneered plastic bottle homes through his Eco-Tec Environmental Solutions, inspired by unconventional building materials like William F. Peck's 1902 beer bottle house. Seeking an inventive waste solution, Froese replaced glass with plastic bottles - abundant, free and unreliaibly degradable. His first African plastic bottle build in Yelwa, Nigeria bonded bottles in walls then sealed them with plaster.

This frugal innovation soon spread for its affordability, sustainability and recycling potential. Groups worldwide emulate Eco-Tec's model, from an 8000-bottle ecological home in Honduras to a PET and wine bottle build in Bolivia. Serbian architect Tomislav Radovanic constructs solely with plastic bottles, while Taiwan and Argentina boast their own plastic architecture. The movement creatively addresses the global plastic crisis while pioneering shelters accessible even to displaced and impoverished communities.

Though originating to aid developing regions, plastic's durability, insulating qualities and customizability continue compelling bottle homes across contexts. Further research into interlocking bottles or reinforcement with traditional materials may uncover even broader potential. What began as pragmatic innovation now propels plastic's purpose towards the cutting edge of design.

This construction technique employs waste PET bottles, debris and earth. Bottles filled with sand, soil, landfill scrapings or mud become brick substitutes, assembled into buildings. Adoption spans Nigeria, South Africa, the Philippines and India among others. To date, over 300,000 bottles have been repurposed across 50+ projects in Honduras, Columbia and Bolivia. Additional nations continue pioneering bottle construction as an affordable, sustainable housing solution. Its modularity also enables custom spaces like studios, garages and disaster relief shelters. While requiring manual labor, material abundance and simplicity minimize specialized skills or machinery. This accessibility allows bottle building to empower and upskill even impoverished communities. As a testament to scalability, the “Eco Dom” nonprofit built over 500 homes in just 10 years using Latin America’s mounting plastic waste. Their model offers both blueprint and motivation for similarly transformative visions of human shelter worldwide.<sup>27</sup> Oscar Mendez, an architect, founded "Conceptos Plasticos" in Bogotá, Colombia. The company uses waste plastic and rubber to create building materials that are used to construct homes for those in need all around Colombia (Winkless, 2016). Carlos Daniel Gonzalez, a native of Mexico, established "EcoDom," a company that collaborates with neighborhood trash haulers in Puebla to accomplish its objectives of lowering plastic waste and boosting the country's economy by producing reasonably priced dwellings out of plastic garbage. The business has used recycled plastic to construct over 500 homes so far. In Argentina, a company called "Eco-Inclusion" is also constructing homes with recycled plastic. This non-profit makes bricks from waste plastic that has been repurposed. The group, which was started in 2014 by businessmen Leandro Miguez, Leandro Lima, and Fabio Saieg, aims to improve Argentina's social situation by offering sustainable and reasonably priced housing. The qualities of a typical brick are also included in "Eco-Inclusion"'s plastic bricks; they are lightweight, insulating, and produced in a way that does not harm the environment<sup>28</sup>. The organization can create 20 bricks in one hour and has 45 locations for collecting plastic in four different cities around the nation. They turn every 20 plastic bottles into one brick. Plastic has also become a popular building material among architects worldwide for creating sustainable, low-income informal settlements in underdeveloped nations.

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<sup>27</sup> Muyen Z, Barna T. N., and Hoque M. N, 'Strength properties of plastic bottle bricks and their suitability as construction materials in Bangladesh' [website] (2016), < [https://www.researchgate.net/publication/311958381\\_Strength\\_properties\\_of\\_plastic\\_bottle\\_bricks\\_and\\_their\\_suitability\\_as\\_construction\\_materials\\_in\\_Bangladesh](https://www.researchgate.net/publication/311958381_Strength_properties_of_plastic_bottle_bricks_and_their_suitability_as_construction_materials_in_Bangladesh) > .

<sup>28</sup> J. Ledur, 'Three Companies Building Houses Made of Plastic - the Borgen Project' [website] (2018), Borgenproject, < <https://borgenproject.org/houses-made-of-plastic/> > .

## UNITED\_BOTTLE

**Place:** exposition in New York, Copenhagen and Zurich  
**Date:** 2007 (first prototype)  
**Designer:** United\_Bottle group  
 (Dirk Hebel, Tobias Klausner, Hanspeter Logo, Jorg Stollmann)

### LOAD BEARING STRUCTURE



## CASAS de las BOTELLAS

**Place:** Puerto Iguazú, Misiones, Argentina  
**Date:** early 2000s (first prototype)  
**Designer:** Alfredo Alberto Santa Cruz

### NOT LOAD BEARING STRUCTURE

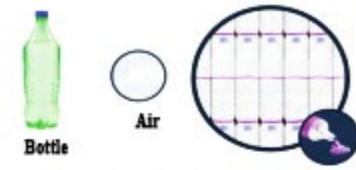


Figure 29: United Bottle (New York, Copenhagen and Zurich): type sheet; Casas de las botellas (Argentina): type sheet.

## METHODOLOGY 1: CONSTRUCTING WITH PLASTIC BOTTLES

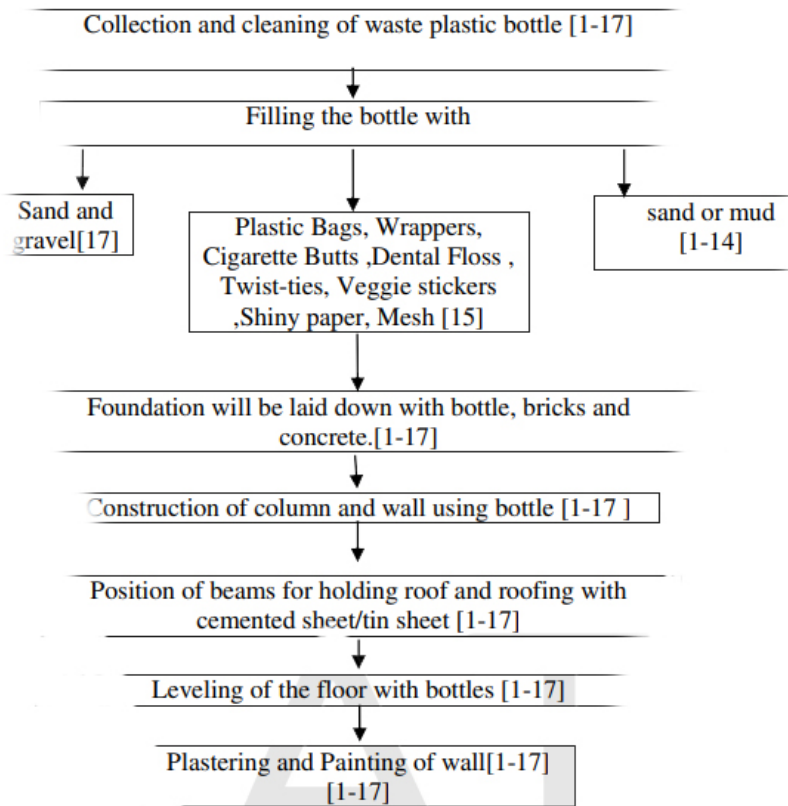


Figure 30: Methodology chart

Since the implementation of separate waste collection, bottles have been given multiple options for end-of-life care: they can be cleaned and reused, put through a process known as upcycling, which turns them into a different product, burned to produce energy, or, in the worst case scenario, end up as garbage and spread throughout the planet (Fig. 1). Consequently, the bottles are sorted, crushed, and packed in recycling centers before being shipped to specialty businesses that insert them into shredders and then sell the finished product to other businesses that recycle raw materials. The plastic that has been reduced to granules can subsequently be converted into fibers, hard plastic, or soft plastic that helps other items get into the market.

Plastic is used in a variety of sectors (Fig. 2): packaging (about 39.7%), building and construction (19.8%), automotive (10.1%), electrical and electronic (6.2%), sports and recreation (4.1%), food and agricultural (3.4%), and others (16.7%) are the sectors that use plastic the most (Plastics Europe, 2018). Taking the aforementioned into consideration, a critical identification and cataloging stage of several case studies was initiated with the goal of contrasting the pros and

negatives, which are shown below, up to the suggestion of a novel construction system utilizing plastic bottles.

### Steps of using plastic bottles to construct

- The first step is to collect plastic bottles, preferably PET bottles, which are widely available and durable. The bottles should be clean and dry, and have their caps and labels removed. The bottles can be of different sizes and colors, depending on the design and availability.

- 
- The second step is to fill the bottles with an infill material, such as sand, soil, clay, or cement. The infill material should be compacted and leveled to ensure the stability and strength of the bottles. The bottles should be filled up to the neck and capped tightly. The weight and shape of the filled bottles will depend on the type and amount of the infill material used.
  - The third step is to arrange the bottles in a module of four bottles that interlock with each other. The module can be formed by tying the bottles together with wire, rope, or tape. The module can be of different shapes, such as square, rectangular, or hexagonal, depending on the design and the type of wall. The module can also be customized by cutting, bending, or joining the bottles.
  - The fourth step is to stack the modules to form a wall, either vertical or horizontal, depending on the orientation of the bottles. The wall should be reinforced by metal or wooden frames and wires, which can be attached to the bottles or the modules. The wall should also be aligned and leveled to ensure the structural integrity and aesthetic appearance of the building.
  - The fifth step is to cover the wall with light panels and insulation layers, such as wood, plastic, metal, or ceramic, to protect the bottles from impacts and weather conditions, and to improve the thermal and acoustic performance of the building. The panels and layers can be hooked up to the frames or the crosspieces, and can be of different colors and textures, depending on the design and the context.
  - The final step is to evaluate the performance and advantages of the construction method, such as its resistance, stability, reversibility, adaptability, and environmental friendliness. The method can also be validated by performing laboratory tests and simulations, such as compression tests and finite element analysis, to measure the stress and displacement of the bottles under load. The method can also be compared with other existing methods of building with plastic bottles, such as using glass bottles or using bottles as containers.

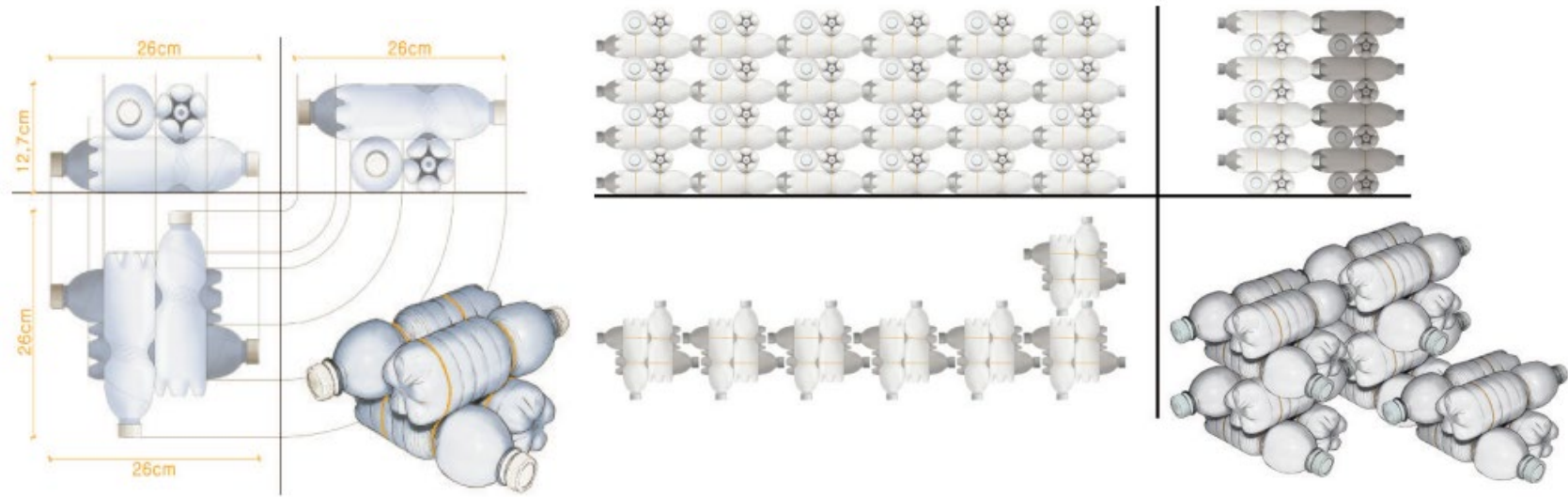


Figure 31: Proposed construction method: Arrangement of the bottles, creation and binding of the brick; Positioning of the bricks.

Evaluation of some variables taken into account in the design choice includes: **the material, the form, the type of filling the bottle, their arrangement and function (structural or not) and finally the type of connection between them.**

This construction method uses PET bottles of 500 ml, with a narrowing at about 2/3 of their height, as bricks. The bottles are filled with sand or earth, and tied together with wire to form a module of four bottles, two lower and two uppers perpendicular to the previous ones. The modules are stacked and locked by the shape of the bottles, creating a stable and compact wall. The wall is also reinforced by vertical and horizontal elements that fit into the spaces between the bottles, and can be covered by light panels for protection and aesthetics.

Laboratory tests: The project validates the new construction method by performing a finite element analysis and compression tests on the modules of bottles. The tests show the strength and stability of the modules, as well as the deformation caused by the load. The tests also confirm the feasibility and versatility of the proposed method, which can be adapted to different contexts and needs.



Figure 32: WoBo Summer House, Netherlands, 1965; Bottle Houses, Canada, 1980-1984 Casa di Bottiglie, Italy, 1999.

Glass has always been the most popular material for liquid containers. These containers come in a variety of shapes and sizes, but they all share the trait of being extremely resilient, making them appropriate for use as bricks even in the absence of any kind of material within. Actually, these are the earliest known instances of bottle-built homes; for more, see Casa di Bottiglie in Italy (1999); Bottle Houses, Canada (1980–1984); and WoBo Summer House, Netherlands (1965). PET bottles are now used as bricks in the assisted design examples that were looked at because of their availability, adaptability, and light weight when being transported. Apart from the material, bottles with various shapes are available in the market (Fig. 27). This allows one to choose the type and arrangement of the most appropriate containers for a given purpose based on the characteristics (Anyanka, 2011). As an illustration, consider the Coca-Cola Company's bottles, which, due to their unusual conical mouth, work especially well when arranged radially to create columns (see: Ecotec Bi4PVS, Africa, Latin America, and India since 2001; Fig. 27).

Bottle Bricks are made of ordinary plastic bottles that have been packed with garbage until they are as small as bricks. This straightforward and easily accessible technology can turn ordinary plastic materials into valuable building materials. Bottle bricks are also referred to as "Portable Landfill Devices" and are commonly known as "Eco-Bricks" or "Eco-Ladrillos" in Spanish. For well over a decade, bottle bricks have been used in Latin America to construct homes, schools, and other buildings. Today, their use is growing globally as a practical means of preventing plastic pollution, cleaning up the environment, and producing a much-needed building material.

In the majority of the case studies that have been examined, the bottle is initially viewed as a container and then as a building material. However, there have been instances in history where the bottle has been perceived as a true "emergency brick" from the beginning, even before it was ever intended to be a container.

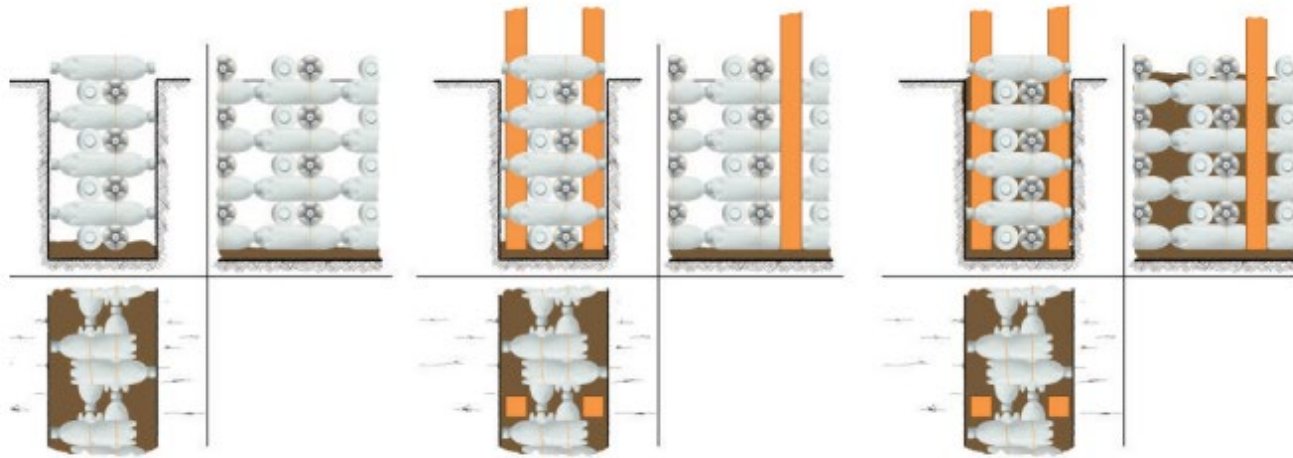


Figure 33: Proposed construction method: Design choices; Construction of the base of the wall.

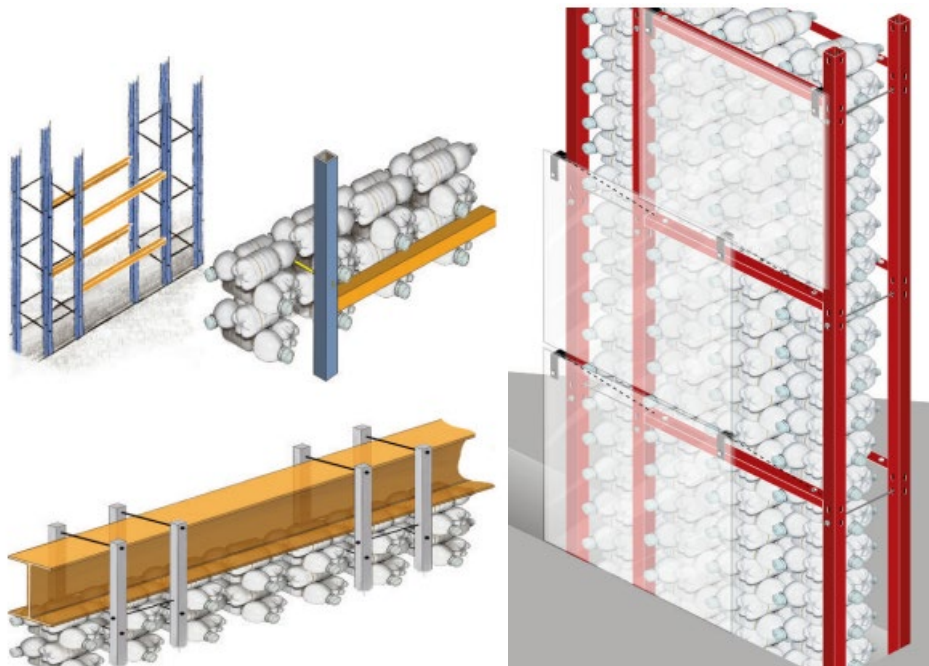
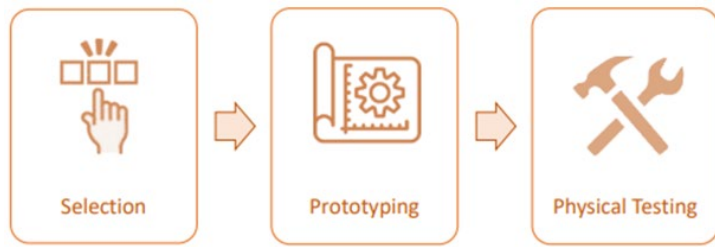


Figure 34: Proposed construction method: Preparation of stiffeners; Creation of the sleeper for the covering; Realization of a possible finish

## METHODOLOGY 2: MATERIAL DESIGN AND ARCHITECTURAL APPLICATION



This literature is derived from a study by Maimuna Shehu 2019 on how to construct low cost in the IDPs of Nigeria. It aims to describe the process of construction with plastic from Waste to structure.

Figure 35: Material design process

### MATERIAL DESIGN



Describes the process of choosing and testing the plastic material for the building component. The main points are:

**1. Selection-PET wastes** are selected as the main material because they are abundant, durable, and easy to process.

Figure 37: Phase one of material design

Material Properties	LDPE	HDPE	PET
Density	917 - 932	952 - 965	1290 - 1390
Tensile Strength Mpa	13.3 - 26.4	22.1 - 31	55 - 60 Mpa
Compressive strength Gpa	10.8 - 17.4	18.6 - 24.8	50 - 60 Mpa
Price USD/kg	1.74 - 1.79	1.61 - 1.65	1.37 - 1.59
Flammability	Highly flammable	Hightly flammable	Highly flammable
Fracture Toughness MPA.m <sup>0.5</sup>	1.21-3.39	1.52 - 1.82	4.42 - 5.64
Melting point °C	98 - 115	130 - 137	260 - 280
Thermal conductivity W/m.°C	0.322 - 0.348	0.461 - 0.502	0.19
Embodied energy MJ/kg	76.2 - 84.1	74.9 - 82.5	51.5-62.9
CO2 footprintt production kg/kg	2.86 - 8.86	2.65 - 2.92	1.45-1.6
Recycle fraction current %	8.02 - 8.86	8.02 - 8.86	20-22%
Water resistance	Excellent	Excellent	Excellent
UV resistance	Poor	Fair	Poor

Table ;Material properties comparison between LDPE, HDPE and PET (CES EduPack, 2019)

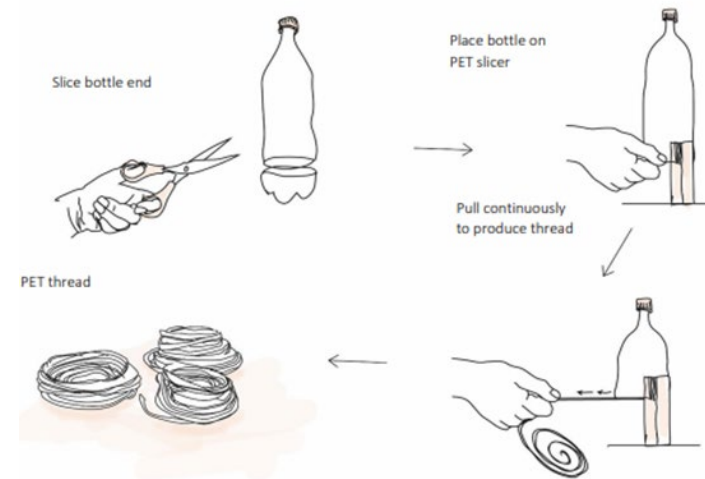


Figure 36How to make Plastic thread from PET.Source Maimunah 2019

Realization aspects	Weegfactor (1-3)	HDPE	PET	Max. score
Availability	3	4	4	15
Cost	3	3	4	15
Ease of collection	3	3	4	15
Ease of shredding for use	3	3	3	15
Ease of reprocessing	3	2	3	15
Processing machines availability	3	2	3	15
Plastic washing ease	3	2	3	15
Total score		57	72	105
Maximum percentage score		54%	69%	100%

Table: Figure 35 Realization aspect comparison between HDPE and PET

Functional aspects	Weegfactor (1-3)	HDPE	PET	Max. score
Density	3	3	4	15
Tensile strength	3	2	4	15
Compressive strength	3	2	4	15
Flammability	3	1	1	15
Fracture toughness	3	2	4	15
Melt temperature	3	2	4	15
Thermal conductivity	3	3	4	15
Water resistance	3	5	5	15
Water absorption	3	5	2	15
Flammability	3	1	1	15
UV degradation	3	2	1	15
Opacity	3	5	2	15
Opacity	3	5	2	15
Total score		84	102	150
Maximum percentage score		56%	68%	100%

Table: Functional aspect comparison between HDPE and PET

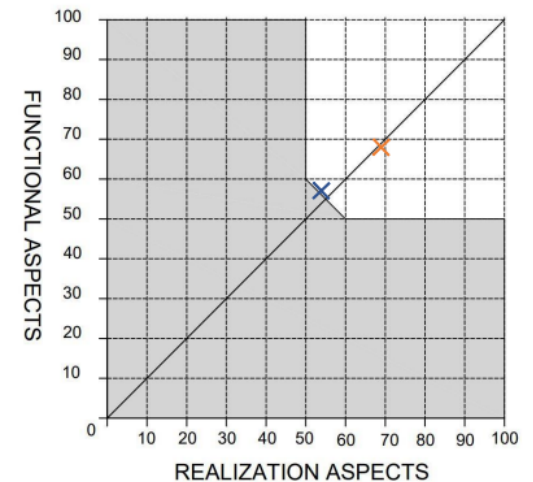


Table: Graphical representation of the functional and realization of HDPE and PET

The findings indicate that if the functional requirements are more important than the realization requirements, then an HDPE component will be more appropriate. On the other hand, since the PET is nearer the line, the functional and realization aspects are in balance. which are both crucial to the building component's production. For this project, PET is the material of choice for construction. **Wood** is used as a reinforcement material to increase the strength and stability of the PET bottles' / **HDPE plastic bags** are used as a binder material to melt and fuse the PET bottles and wood together.

**2.Prototypes** are made using different methods of cutting, stacking, and melting the plastic materials. The best method is to cut the PET bottles into rings, stack them with wood pieces, and melt them with LDPE/HDPE plastic bags using a heat gun.

- The initial idea of interlocking plastic bricks is discarded due to the high cost and complexity of the injection molding method.
- The final idea is to use flat and wide sheets of PET bottles filled with sand and tied with wire, which are more suitable for a low-cost and low-tech application.
- The PET sheets are designed to fit the wooden framework system preferred by the camp residents, and to be stiffer than the polyethylene sheets currently used.

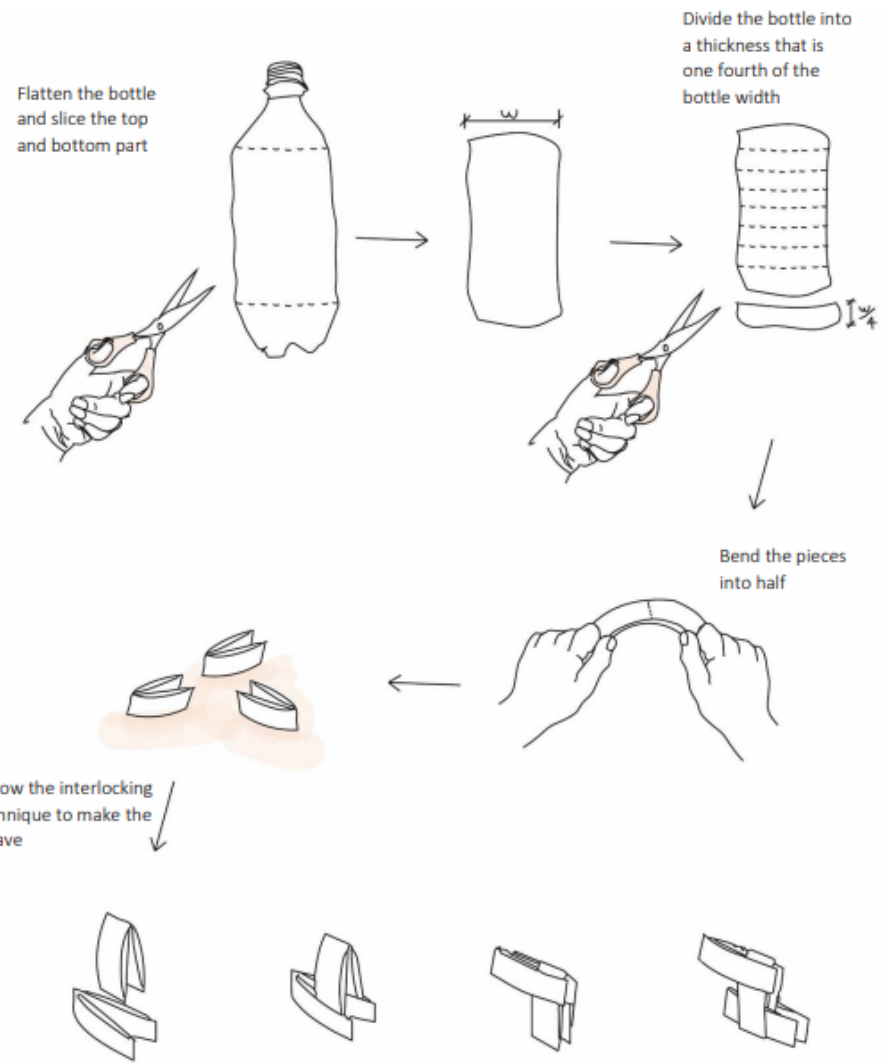
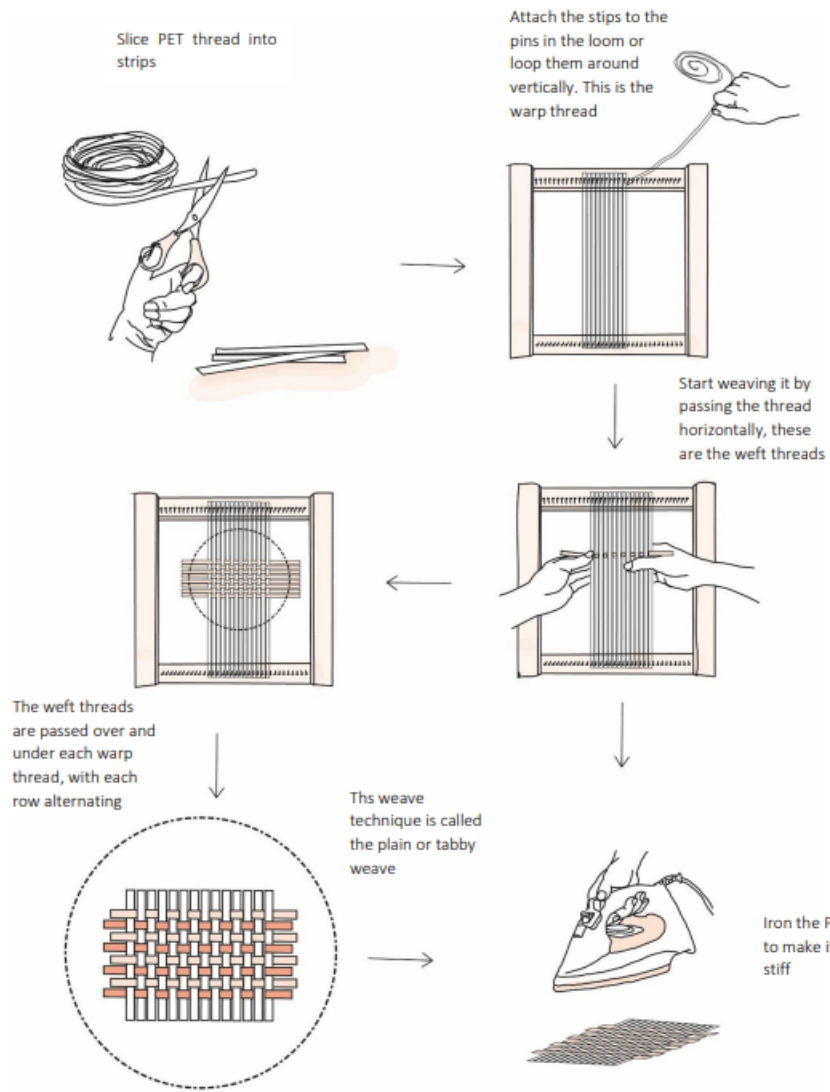
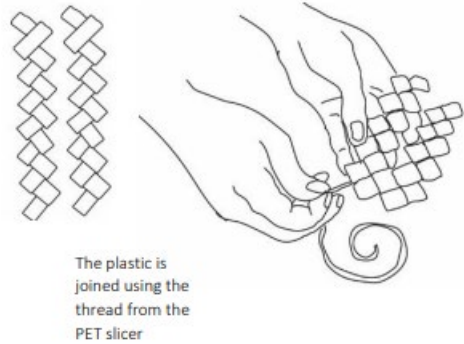


Figure 38 Figure 39 How to make Plastic panel from PET. Source Maimunah 2019

- The PET sheets are made by cutting, stacking, and melting PET bottles with polypropylene fabric, which increases the rigidity, opacity, and crystallinity of the material.



To further prevent needless seams from forming when separate long strips are joined together, the plastic could be continuously woven. To allow for an extension of the plastic in this instance, the strip thickness is one-sixth of the bottle width. To further tighten the plastic's hold, utilize PET thread. This is a continuous piece that, when heated, becomes opaque and fairly stiff. Prior to heating, PET thread can be used one more time to reinforce the weave's tightness.

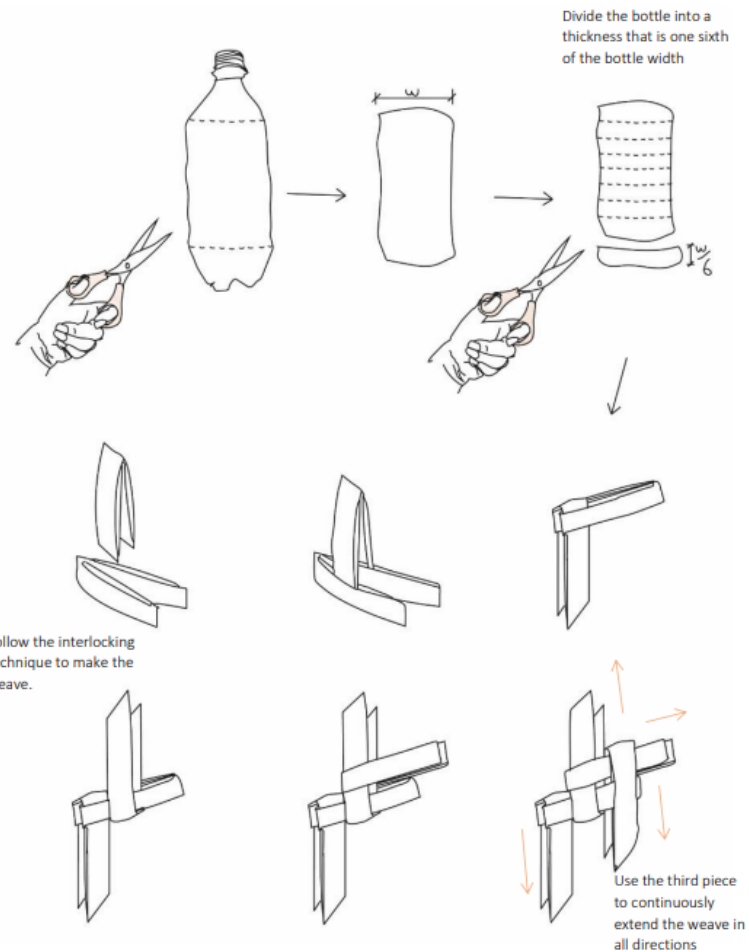


Figure 40 Process continued Maimunah 2019

### 3. Physical Tests

The prototypes' mechanical attributes, such as their tensile, bending, and compressive strengths, are measured physically. The outcomes demonstrate that the prototypes are strong enough to be employed as structural elements. The tensile strength increases with weave tightness. It might be preferable to the camp's current single layer of cement bags. The tightest weaving technique is required to achieve the highest tensile strength for the woven PET.

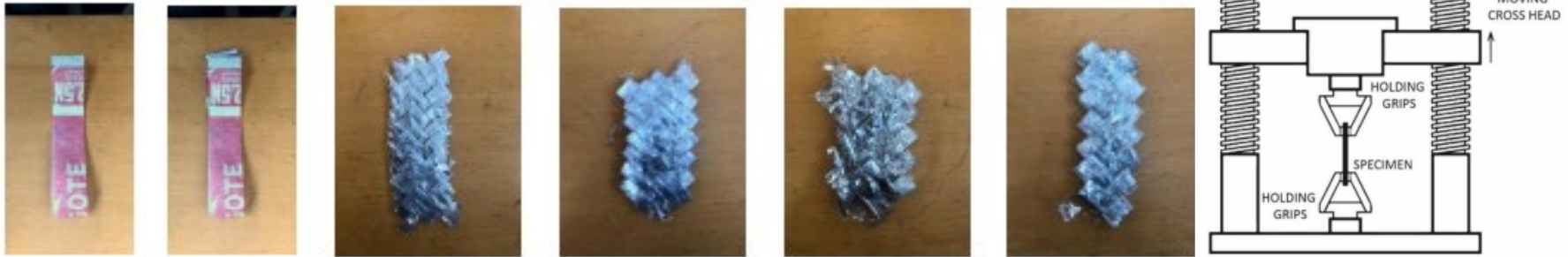


Figure 41 Plastic panel quality test. Mimunah 2019

### ARCHITECTURAL APPLICATION

**1. Panel configuration and geometry** are determined by the size and shape of the PET bottles and wood pieces. The panel has a rectangular shape with a dimension of 60 cm x 40 cm x 10 cm. The panel has a hollow core with a honeycomb structure to reduce weight and increase insulation.

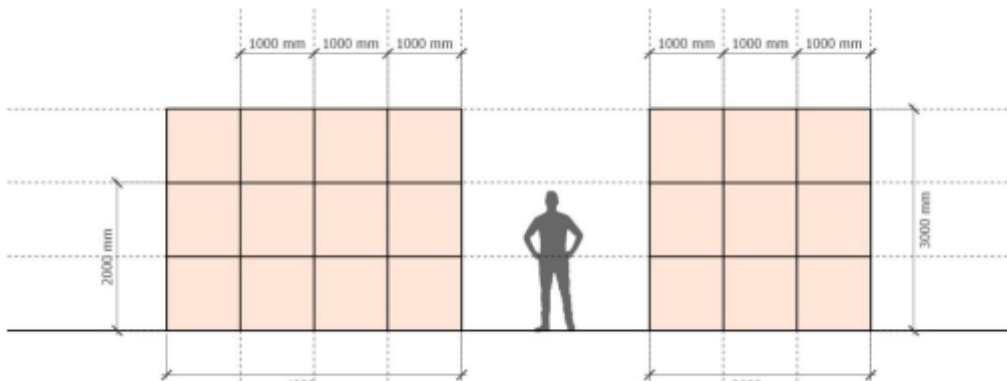


Figure 43: Chosen grid for the panel geometry

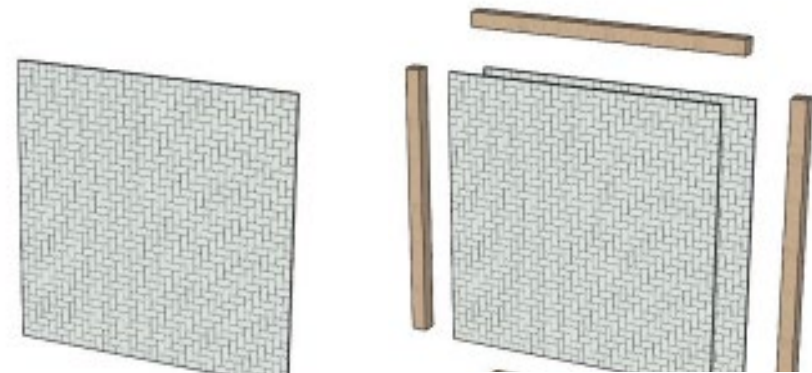


Figure 42: Classification of PET building component. A-sheet B-Composite

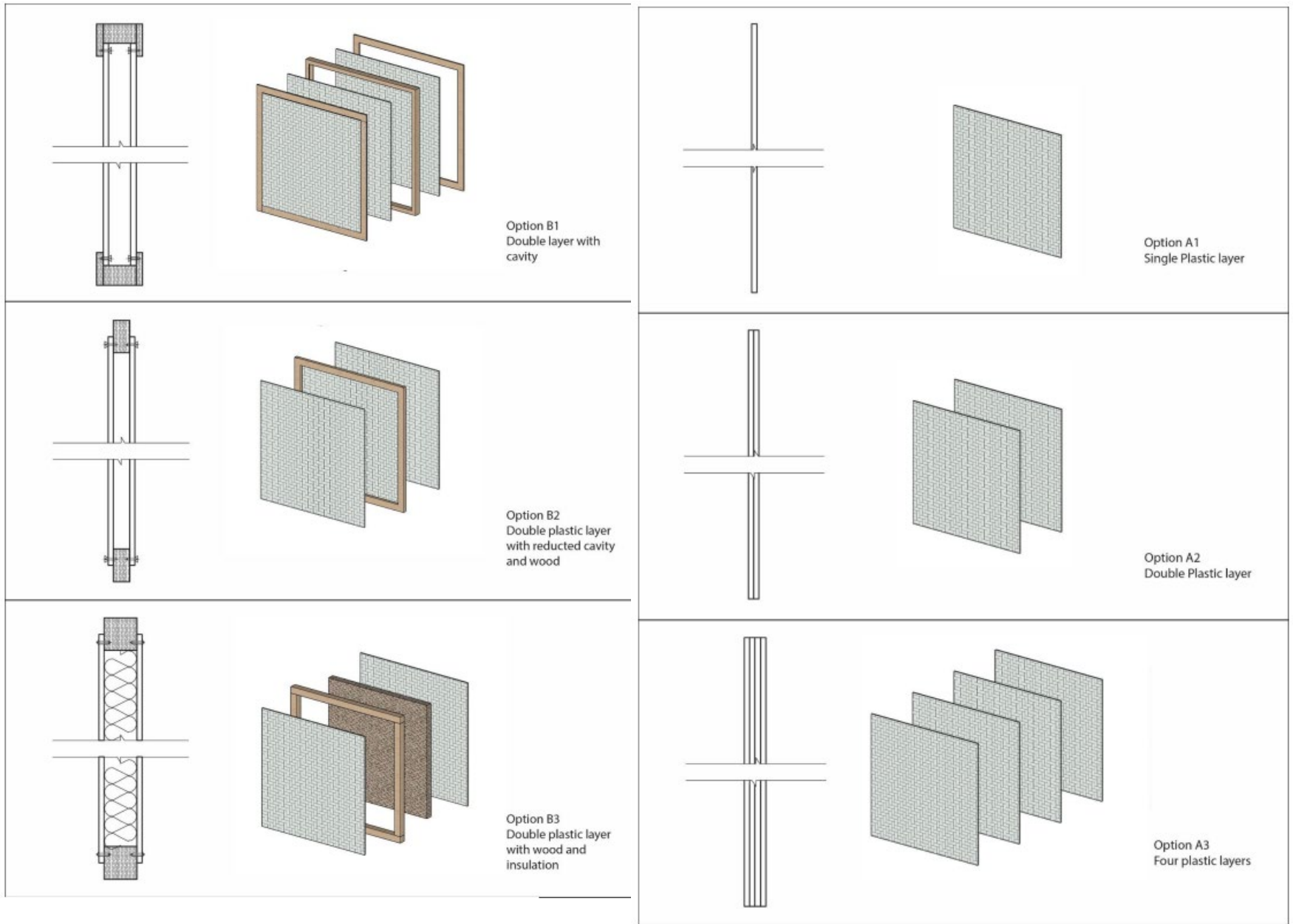


Figure 44:  
Panel  
configuration  
options

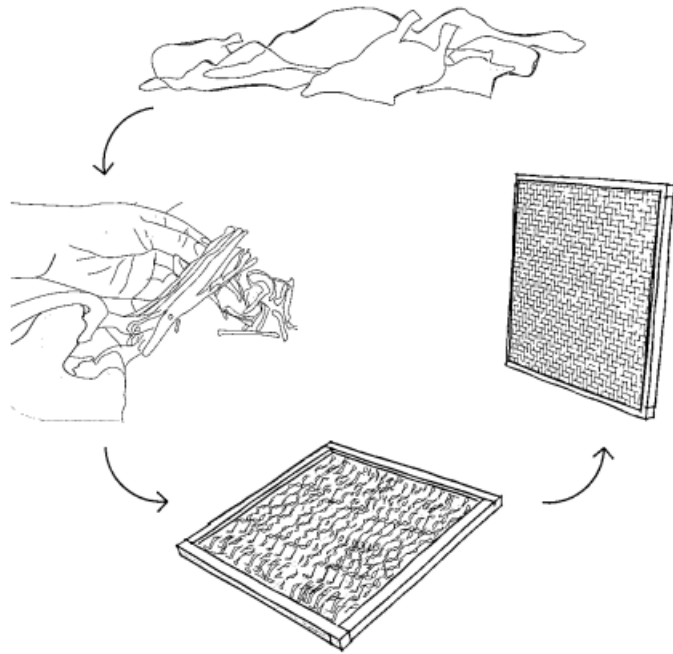


Figure 45: Shredding HDPE to use as insulation.

**2. Building system** is designed to be modular, flexible, and adaptable. The panels can be connected horizontally and vertically using bolts and nuts. The panels can also be arranged in different patterns and orientations to create various forms and functions.



Figure 46: Wooden frame-work and composite plastic facade building component

Panel-

1. 8mm woven plastic (26 large bottles or 52 smaller bottles/m<sup>2</sup> )
2. Wooden panels
3. Wooden frame columns and beams
4. Insulation made from sliced plastic – 200 bags /m<sup>2</sup>

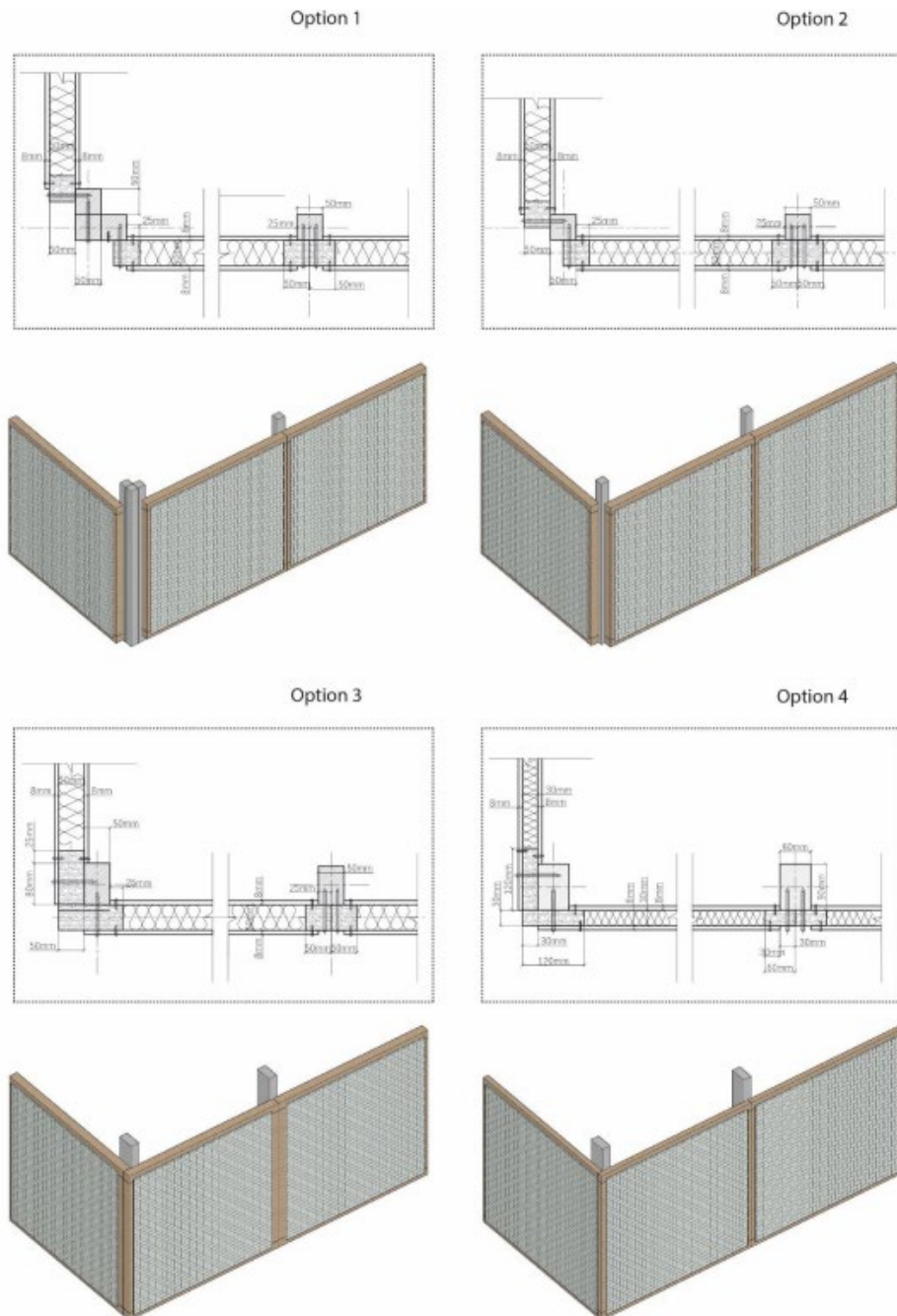


Figure 47: Panel connection options

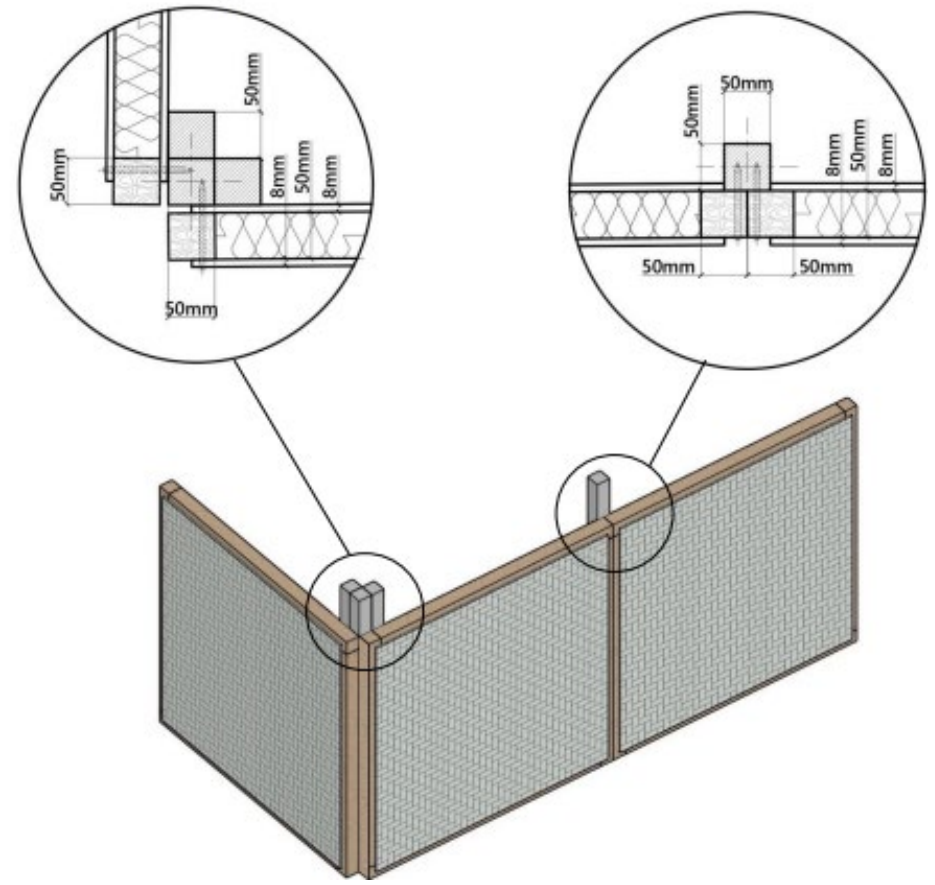


Figure 48: Option 5 (picked option)

**Option 1** uses the same 50mm thick wood for both the columns and the panels.

**Option 2** reduces the amount of material used by joining the corner panels to a single column, but the column is still visible. As a result, there might be needless gaps and the joint may not look as nice as it could.

**Option 3** makes certain that the corner joint is neat and closed. In addition to using fewer materials overall, this option has a stronger connection with the screws than the previous two. There are differences in the thicknesses, though.

**Option 4** depicts the identical corner connection as option 3, but with a wood panel that is 30 mm thick rather than 50 mm. Additionally, the column sizes are now 60x90 mm instead of 50x80 mm. This aids in establishing a standard for the measurements and gives adequate room for the screws to be fastened to the structure. The main problem with this is that it produces corner panels with disparate sizes. To reduce waste and facilitate construction, the panels are to be as uniform as possible.

**Option 5** demonstrates the best possible connection between panels and a corner column composed of 50 mm thick wood. The building system is incremental in nature and is easier to construct, assemble, and disassemble because there is no variation among any of the building components. The diagram below shows the grid of the building system.

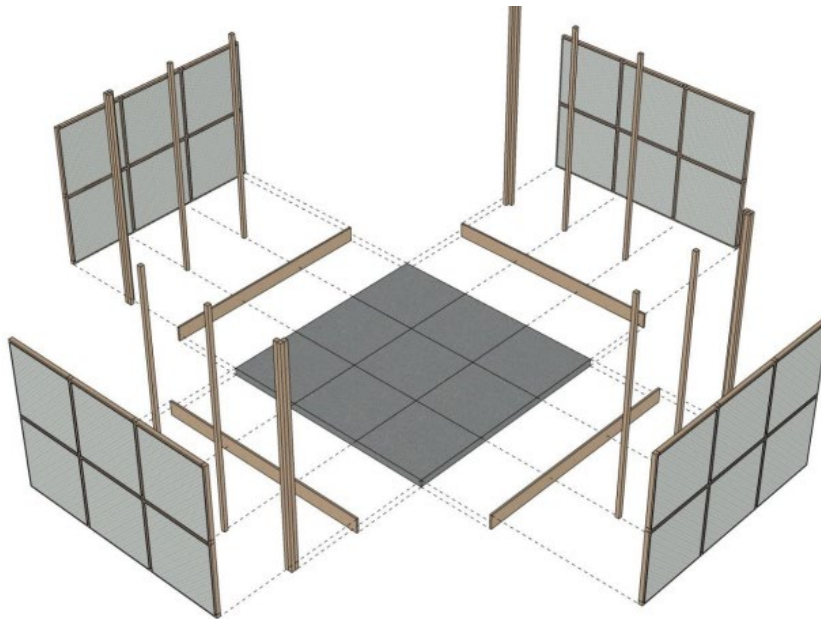


Figure 50: Exploded axonometric view of the building system

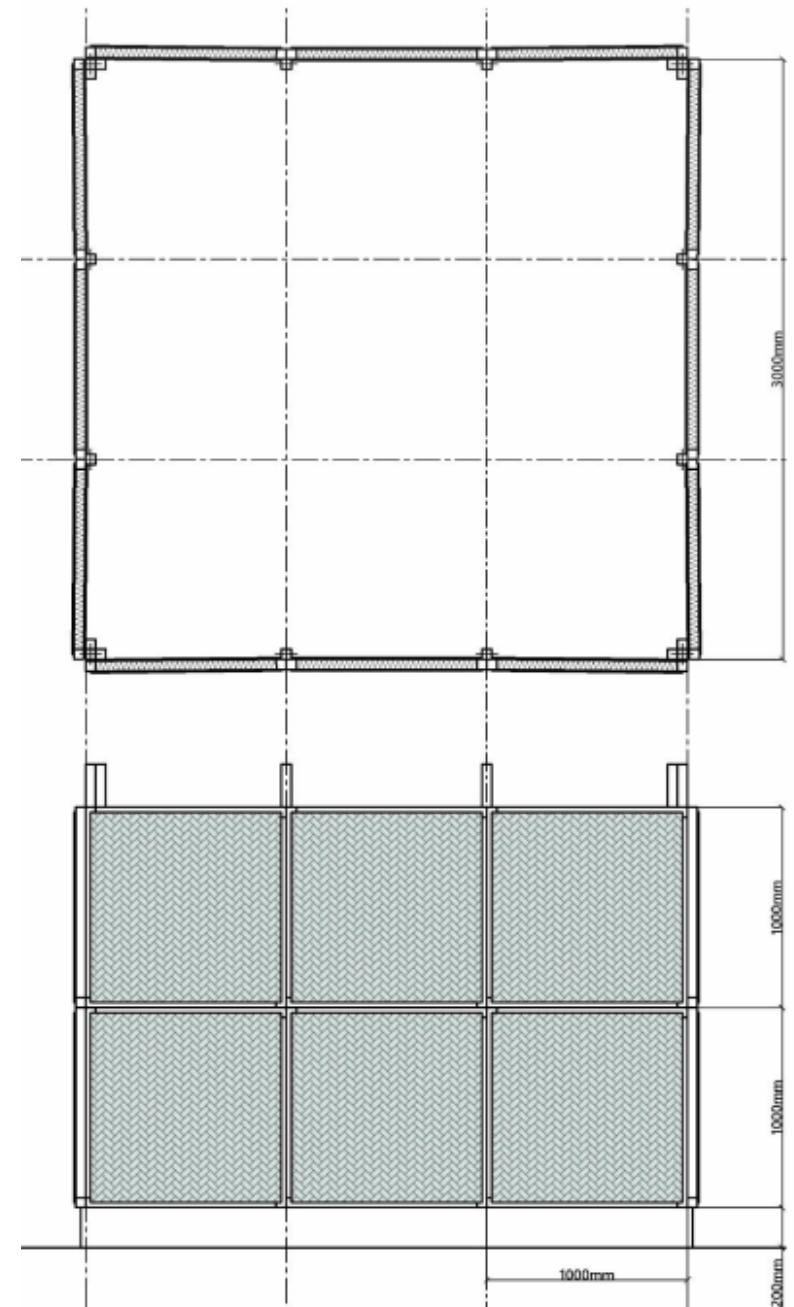


Figure 49: Grid system and elevation

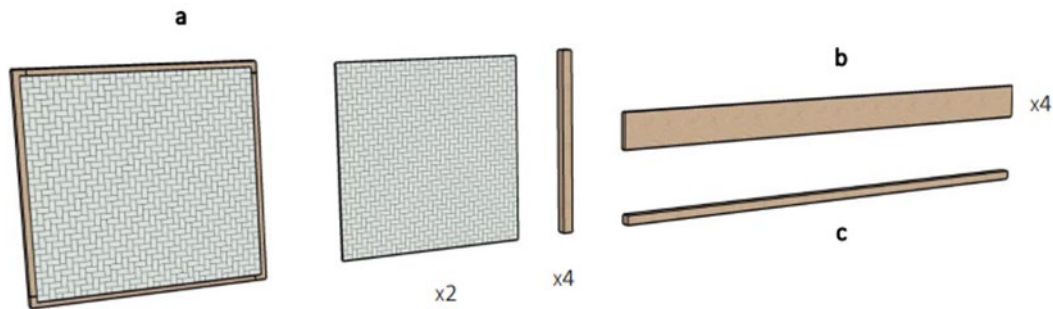


Figure 51: Building system components

- a. 950x950 woven PET
- b. 25x200x300mm base wooden panel
- c. different bar lengths 50x50mm thickness)

**3.Bioclimatic building design** is considered to optimize the thermal comfort and energy efficiency of the building. The design uses passive strategies such as orientation, ventilation, shading, insulation, and daylighting to reduce heat gain and enhance natural cooling.

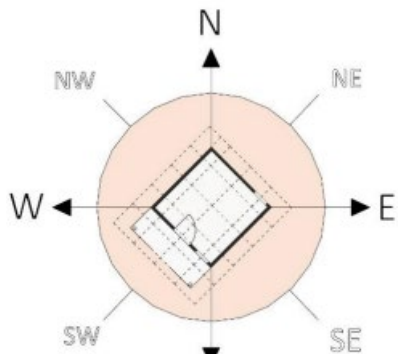


Figure 53: Optimal climate house in Kuchingoro IDP camp

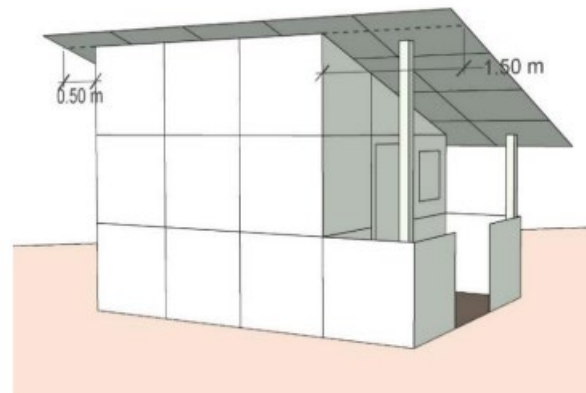


Figure 54: Overhang dimension

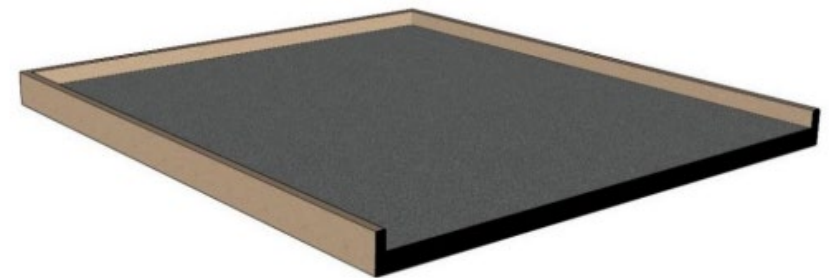


Figure 52: Concrete base with wood panel insulating it

**4. Architectural design** is developed for different family scenarios, such as single, couple, and large family. The design provides basic facilities such as sleeping, cooking, washing, and storage. The design also allows for customization and expansion according to the needs and preferences of the users.



TYPE A

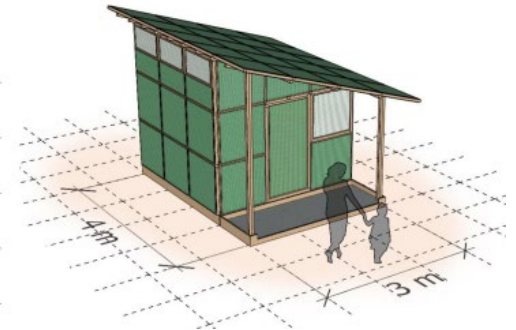
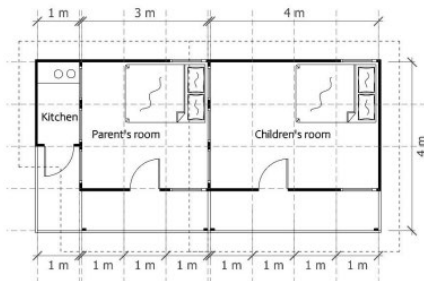


Fig 45

TYPE B



TYPE C

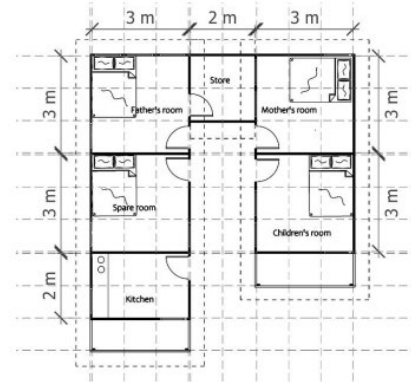


Figure 58: Section through Bacha A configurat

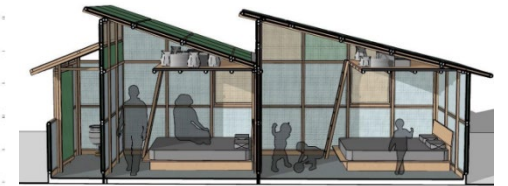
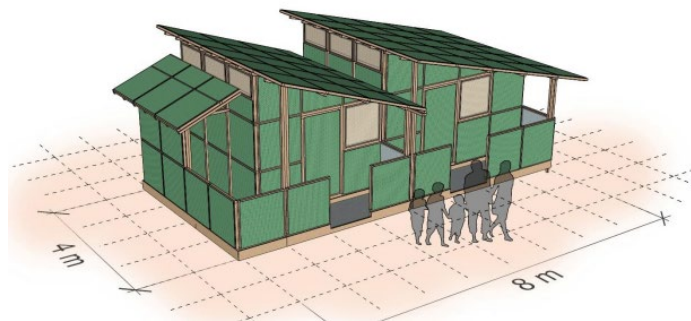


Figure 57: Section through Bacha B configuration

Figure 56: Bacha B configuration

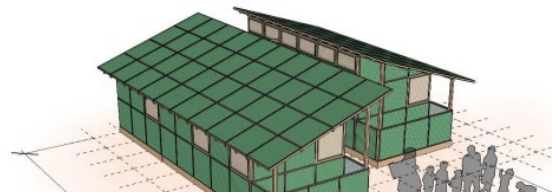


Figure 55: Bacha C configuration



Figure 59: Section through Bacha C configuration

**5. Building sequence** is illustrated to show how the building component can be easily assembled and disassembled by the users. The sequence involves four steps: foundation, frame, enclosure, and finishing.

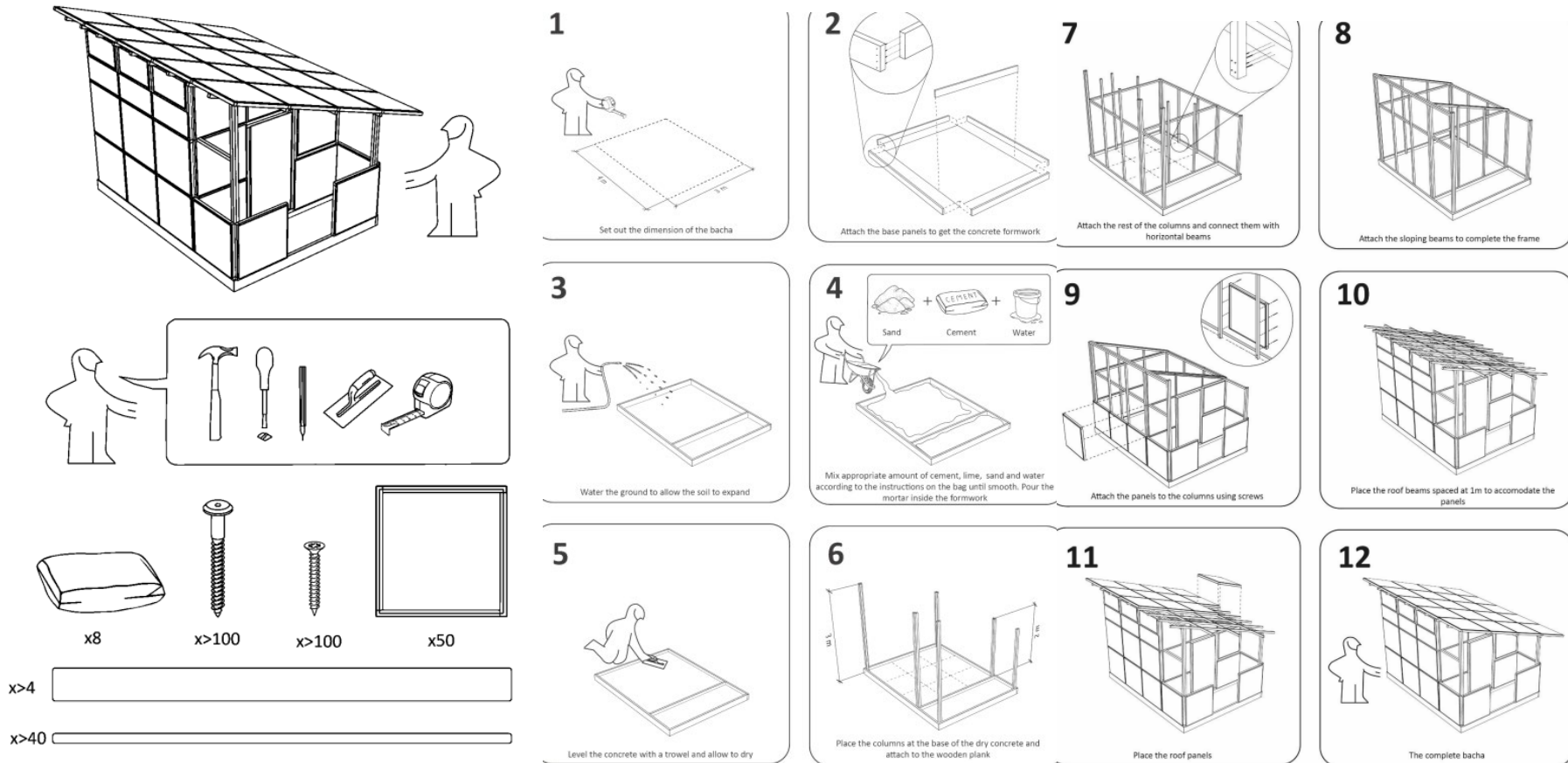


Figure 60 Panel construction Maimunaah 2019

**6. Physical prototype** is made to demonstrate the feasibility and appearance of the building component and the architectural design. The prototype is scaled at 1:10 and uses the same materials and methods as the real component.

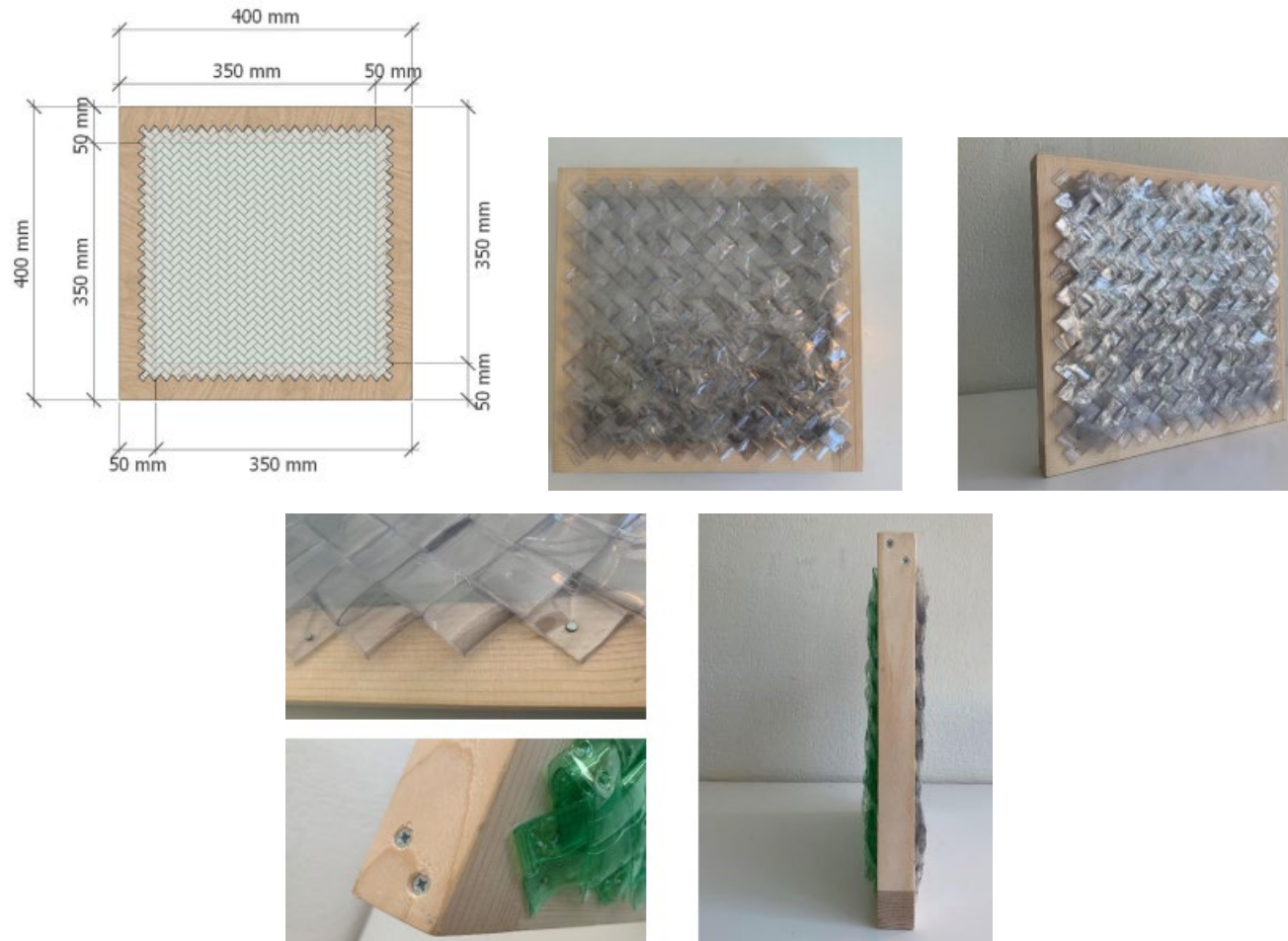


Figure 61 Panel Construction Source Maimuna 2019

The colored plastic is thicker and more difficult to lay flat on the wood, which is the main lesson to be learned from building this model. To keep it in place, more nails will be needed. Additionally, it's a good idea to weave in a little bit of leeway to allow for plastic contraction in the event of heat application and, in theory, when exposed to the sun for an extended period of time. The panel weighs 3.2 kg in total.

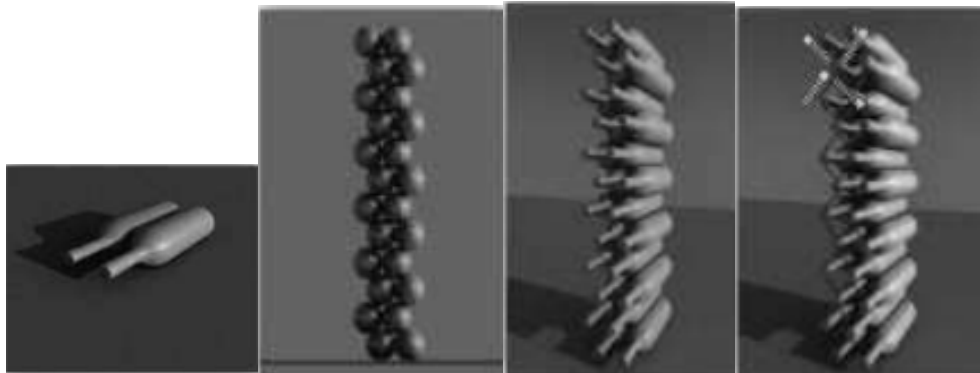
## 2.4: BENEFITS AND CHALLENGES OF BUILDING FROM PLASTIC WASTE

### 2.4.1: ADVANTAGES OF BUILDING FROM PLASTIC BOTTLES

It's fascinating to note that plastic bottles are just as strong as bricks, ceramic blocks, and concrete blocks, but they also come with a lot of benefits. As previously mentioned, Andreas Froese, who also founded ECO-TEC\_, presented this creative idea for the first time in order to offer guidance on solid waste utilization and environmental management. Brick is replaced with plastic bottles using the green building ECOTEC technique. Reusing plastic can be a good way to solve this issue because it doesn't break down quickly, leaving it as trash on the planet for a long time. When comparing these cutting-edge substitute materials to more traditional materials like brick, the following are some of the main advantages:

#### **Good construction ability**

Because the walls made of these bottles are lighter than those made of brick and block, these buildings exhibit good seismic resistance. Each bottle's resistance to the load is 20 times greater than that of a brick because of the compaction of the filling materials. Additionally, the plastic bottle is stopped from passing the shot by these compressed filling materials, which turns the building into a bulletproof shelter. The self-supporting nature of the bottle wall, which allows the bottles to be stacked crinkly on top of one another, is another feature that makes it an excellent wall. The bottle's front and back cross-shaped cables will clash with one another, creating a force field that pushes the cables in opposition to one another throughout the entire assembly. The bottle shapes and their proper placement on each other are shown in Figures 3 and 4, respectively. These figures were created through simulation using 3D Max software.



*Shape of plastic bottles, the way of putting the bottles on each other Source Andrea -2013*

## Low cost

We can save 45% on the final cost of building a house by using plastic bottles for the walls, joist ceiling, and concrete columns. When different cost components are broken down, it can be seen that using local labor to make bottle panels can result in cost savings of up to 75% when compared to building walls with brick and concrete blocks. It should be mentioned that highly skilled labor can result in shorter construction times and lower relative costs.

## Suitable thermal behavior

The creative solution is to fill each bottle with three layers to insulate these panels against heat exchange. Sand and compacted gravel should fill the bottle's front and back, while wood or cork fragments should fill its center. Cork is regarded as an impenetrable insulator and is utilized in cylinder components to prevent glass and bottles from passing through.

Approximately 60% of all cork produced worldwide is used to make bottle caps, which are then discarded after being used. However, 60% of that cork can also be recycled and used to make these panels, which can be useful and productive. A range of materials that are suited to the intended location can be used to construct the panel. However, mud is the substance that produces a positive outcome. Mud can be used as thatch or combined with wood particles to fill in the spaces between bottles and make them look more beautiful.

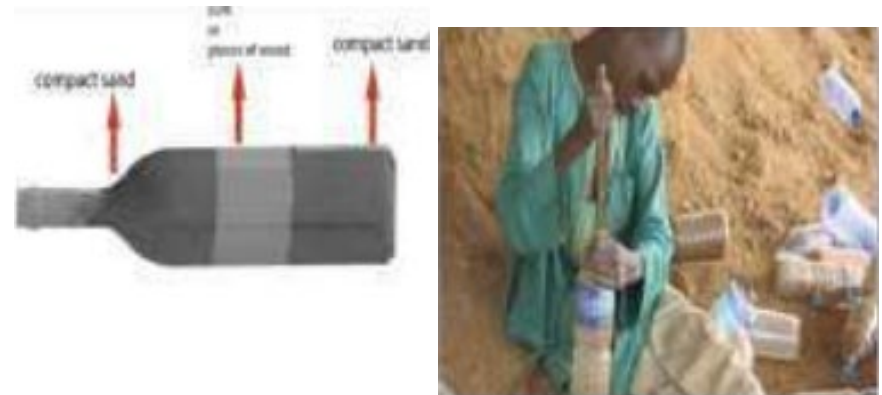


Figure 62 Method of filling the plastic bottles for using in the building



### **Non-brittle characteristic**

Reducing construction waste can be achieved by using non-brittle materials. Plastic bottles are not brittle like bricks are. Brick produces a higher percentage of construction waste than plastic bottles because of its frangibility property. A sample of broken brick used for the walls is shown in Figure

*Figure 63 Brittleness characteristic of the brick*

### **Absorbs abrupt shock loads**

One quality that improves a building's performance against an unforeseen load is flexibility. The plastic bottles can withstand sudden loads without breaking because they are not brittle. This feature may also improve the building's ability to withstand earthquakes.

### **Green Construction**

By reducing emissions, recycling materials, conserving energy and resources, having major operational savings, and boosting workplace productivity, plastic bottles can contribute to green construction. Two examples of actual green buildings constructed with plastic bottles are displayed in Figure 59.



*Figure 64 Green buildings built using plastic bottles*

### **2.4.3: Summary of Benefits of building from Plastic Waste**

- i. Lowering the waste management's related expenses. By reducing the quantity of plastic waste in landfills, plastic waste management lowers storage expenses.
- ii. Reduced cost of building supplies. When compared to traditionally used materials, PET is incredibly inexpensive to recycle and reuse because it is a waste and requires expensive storage. The financial advantages are numerous and include reduced dump maintenance costs for the plastic waste recycling company, extremely low prices for the raw materials used in the recycling plant, and extremely low prices for the raw materials processed in the construction material manufacturing plant.
- iii. Development initiatives across numerous nations. There are development and implementation programs in many countries with high pollution levels from plastic waste, as well as in many others, to adapt plastic raw materials for industrial reuse. As a result, more money is available to support these kinds of endeavors, and the businessperson who is interested in the waste material may be eligible to receive a grant for this reason from the state.
- iv. Enhancing the qualities of materials fabricated from PET recycling. PET-based cement-based materials don't exhibit any weaker strength characteristics when compared to traditional cement composites. The main reason for their lower absorbability is the extremely low absorbability of PET waste itself. PET-based building materials have a greater resistance to bio corrosion.
- v. Lessening a building's energy requirements. Utilizing plastic wastes to create insulation materials enhances a building's energy efficiency and lowers maintenance costs.
- vi. PET wastes have low transportation costs. This kind of waste is available practically anywhere locally. When they are used instead of natural raw materials, which sometimes have excavation sites far from the locations of their applications, the costs of transporting waste to the target processing plant are decreased. Additionally, this strategy lowers other transportation-related pollutants and CO<sub>2</sub> emissions.

### **2.4.4: Challenges of building from plastic waste**

A number of risks and restrictions related to the possible use of PET wastes were also described, based on the literature review. The following is a list of the most significant ones:

- i. High contamination with varying compositions can occur occasionally. PET wastes are frequently contaminated at a later processing stage with other materials, which are typically specks. In these situations, removing the speck components necessitates the application of additional treatment.
- ii. The general public is ignorant of the safety of PET wastes mixed into building supplies. PET wastes contained within the building material matrix pose no threat to the environment or the occupants of the building constructed using said material. Reusing plastic waste usually lessens its harmfulness, even though it is still regarded as extremely hazardous waste. Regretfully, this problem is still largely unknown to the general public.
- iii. Inadequate guidelines and rules regarding the utilization of PET waste in the production process of building materials. The results of scientific research and development projects serve as the foundation for the great majority of PET waste applications currently in use. Their commercial application is limited due to the lack of standards for their processing and methods of integration into building materials.
- iv. Poor interface between the construction material matrix and PET wastes. This is one of the primary issues with PET use in the building sector, but it also applies to other plastic waste. This is mostly because PET wastes have low surface energy, which can occasionally cause the mechanical cohesiveness of the final composite to be compromised.
- v. Ignorance of the building materials' long-term performance when combined with PET wastes. The long-term durability of recycled construction materials is still unknown because this is a relatively new trend in building materials engineering. Therefore, contractors occasionally express concerns regarding the commercial use of wastes for this purpose<sup>29</sup>.
- vi. Compositional variation. Because PET products are produced in a range of grades, species, and types, there may be differences in the qualities of the various assortments. This calls for the creation of methods for classifying PET wastes based on their individual characteristics. This will make it possible to properly design and regulate the characteristics of PET building materials.
- vii. The typical low density of waste made of PET. Low density is preferred in some construction applications, such as lightweight structural concretes or insulating materials. This frequently restricts their use in situations requiring a high degree of stiffness and strength.

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<sup>29</sup> H. H. Rahat, Massarra C. C., and Wang G, 'Using Plastic Wastes in Construction: Opportunities and Challenges' [website] (2022), Conference: ASC2022. 58th Annual Associated Schools of Construction International ConferenceAt: Atlanta, Georgia, <  
[https://www.researchgate.net/publication/359798882\\_Using\\_Plastic\\_Wastes\\_in\\_Construction\\_Opportunities\\_and\\_Challenges](https://www.researchgate.net/publication/359798882_Using_Plastic_Wastes_in_Construction_Opportunities_and_Challenges) > .



time perspective could even bringing new potential for business and investments for self-sufficient habitats. *'When littered, the economic impact of plastics encompasses not just the lost economic value in the material, but also the costs of cleaning up and losses for tourism, fisheries and shipping'*-(European Parliament, 2018)

### 2.5.1: Environmental Impact

Reusing plastic bottles is regarded as a sustainable consumption pattern because it creates a feedback cycle after use. The pattern adheres to the reusing and recycling process since it won't produce waste. The sustainable consumption pattern is shown in Figure 8. In a sustainable consumption pattern, reusing processes can save a significant amount of embodied energy that would otherwise be wasted. Because plastic bottles can be reused, using them in building construction can help save a lot of high embodied energy. This large decrease in embodied energy has the potential to mitigate global warming, reduce resource consumption, decrease biodiversity, and ultimately enhance the built environment and public health<sup>30</sup>.

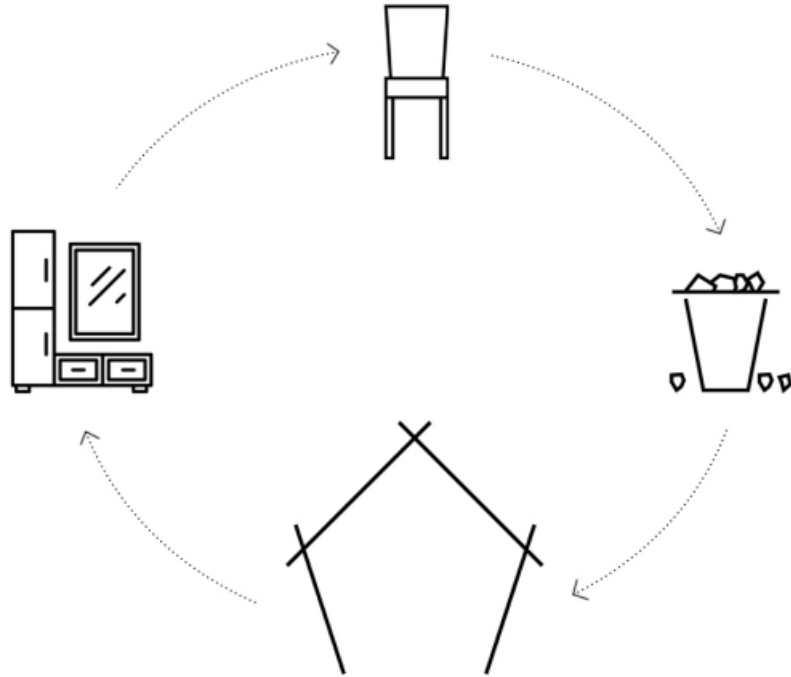
By using bottle panel technology, the carbon emissions that are released when a regular brick is baked are reduced. This technology can lessen the quantity of cement needed for the building's walls, which in turn can lessen the amount of heat produced by cement factories. As a result, less greenhouse gas is released into the atmosphere, slowing down global warming and halting ozone depletion over time. In comparison to conventional roofs, this material can also be used for the building's roof, providing superior insulation. It may result in lower heating and cooling expenses. Thus, it can be concluded that compared to clay bricks, bottle bricks are significantly more energy-efficient.

It also tackles the problem of micro plastics and mismanaged plastic waste reaching the oceans. Upcycling to an application such as housing, increases the lifespan of each piece of plastic for more than 10-20 years. Furthermore, due to its lightness, constructions from plastics saves energy and CO2 emission from transportation. A single room building, with the tiles of 20mm thickness for better resistance, joinery and insulation, can be made out of around 1 ton of plastics. According to OurWorldInData, until 2015, 7.8 billion tons of plastic was created in the world (Ritchie and Roser, 2019). The number is bigger than the global population. That means that not only there is enough plastic waste for each person around the world, but also, if right now every person in the world builds at least a small house for himself, mismanage plastic would no longer be an environmental crisis and there would be no plastics in the ocean and other natural habitat polluting flora and fauna.

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<sup>30</sup> P. Awoyera, and A. Adesina, 'Plastic Wastes to Construction Products: Status, Limitations and Future Perspective', *Case Studies in Construction Materials*, 12 (published online 2020), < <https://doi.org/10.1016/j.cscm.2020.e00330> > , E00330.

## 2.5.2: Driver of Circular Economy



Created for recycling, Plastic Architecture introduces a building model which is not limited to a single use. Material properties analysis have shown the possibilities for plastic upcycling more than once and the design strategy relies on pure use of polymers without mixing between each other and without using additives. The possible scenario sees plastic waste as an input for increasing the condition of a small housing unit / shelter. Keeping in mind that the living conditions could make an impact on economic level of residents and shelters may no longer be needed in a time period of several decades, tiles are designed to be shredded later on for the same purpose or to create interior elements such as furniture, wall finishing or decor. Even though plastics are artificial material and the process of reusing it cannot create a full circle, the use of plastics in a long-lasting application such as architecture allows us to maintain the quality of material without deterioration for the longest time period possible<sup>31</sup>.

<sup>31</sup> S. King, and K. E. Locock, 'A Circular Economy Framework for Plastics: A Semi-Systematic Review', *Journal of Cleaner Production*, 364 (published online 2022), < <https://doi.org/10.1016/j.jclepro.2022.132503> > , 132503.



Figure 66A community collection center, India 2016

### 2.5.3: Social Integration

Communities affected by plastic pollution should have access to education on this topic. There is a growing number of people, who see plastic recycling as an opportunity for getting some money. People are voluntarily gathering for the cleanups all over the globe. It is crucial to spread awareness not only how to separate plastic items, but also how to use it to the fullest benefits, for example how to, with a little more effort, people can improve their living conditions and potentially health of them and their family<sup>32</sup>. An example in Bhopal, India shows that by supplying awareness and introducing little help of social security to already existing recyclers, the community is gathering together to improve its environment and earn extra money for their families. Moreover, the particular example shows how recycling empowers and creates alternative workplaces to women, who now are able to provide education to their kids.

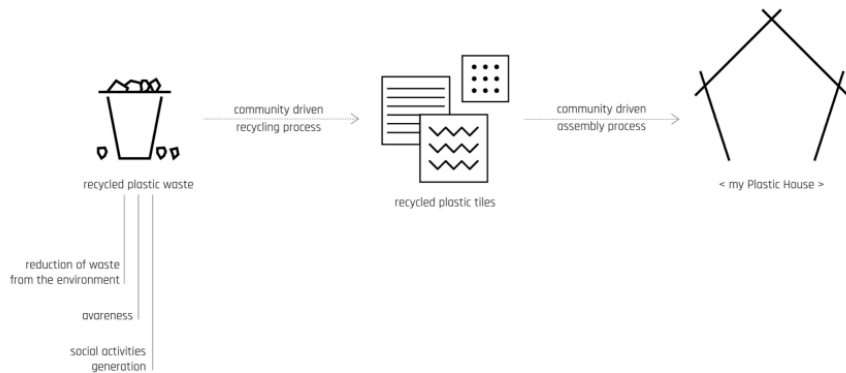


Figure 67Global Environment Facility. (2018). Plastic management system improves livelihoods of Bhopal women, helps the environment. Accessed 24 Sep. 2019

<sup>32</sup> G. Jureviciute, 'Plastic Emergency Architecture - Creating low-cost, accessible architecture from waste material, improving livability in areas affected by mismanaged plastic waste' [website] (2019), < [https://www.researchgate.net/publication/339295073\\_Plastic\\_Emergency\\_Architecture\\_-\\_Creating\\_low-cost\\_accessible\\_architecture\\_from\\_waste\\_material\\_improving\\_livability\\_in\\_areas\\_affected\\_by\\_mismanaged\\_plastic\\_waste](https://www.researchgate.net/publication/339295073_Plastic_Emergency_Architecture_-_Creating_low-cost_accessible_architecture_from_waste_material_improving_livability_in_areas_affected_by_mismanaged_plastic_waste) > .

## 2.6. CONCEPTS IN PLASTIC WASTE AND ARCHITECTURE

### 2.6.1: Sustainable Development

Development that satisfies current requirements without jeopardizing those of future generations is known as sustainable development, or SD.

Utilizing waste plastic to construct can adhere to SD goals. It can help prevent or lessen environmental degradation processes like land filling through reuse, prevent the depletion of resources, protect the environment, and help achieve social equity by preventing the gap between the rich and the poor in society. Figures 1 and 2 show the present face of SD and its potential future face, respectively<sup>33</sup>.

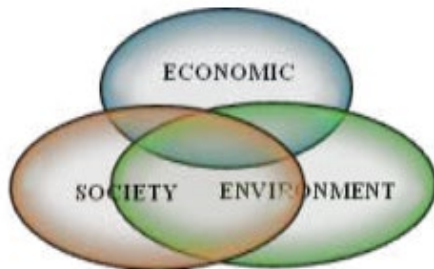
The following are some possible goals for SD:

**Resource conservation:** To protect non-renewable resources, like fuel, minerals, and other supplies, in order to guarantee a sufficient supply for both the current and future generations.

**Built development:** To respect the natural environment by incorporating environmental considerations into planning and development.

**Environmental quality:** to stop or lessen actions that degrade the environment, like land filling, and to promote a culture of recycling and reusing.

**Social equity:** To promote the pursuit of social equality and to obstruct development that widens the gap between the rich and the poor. One sustainable material that can aid in accomplishing the SD is plastic bottles.



*Fig. 1 Face of SD at current time*



*Fig. 2 Alternative face of SD in future*

<sup>33</sup> R. Kumar et al, 'Impacts of Plastic Pollution on Ecosystem Services, Sustainable Development Goals, and Need to Focus on Circular Economy and Policy Interventions', Sustainability, 13/17 (published online 2021), < <https://doi.org/10.3390/su13179963> > , 9963.

## 2.6.2: Green building

A "green building" is any environmentally sustainable structure that is designed and maintained with the intention of reducing negative environmental effects, such as the depletion of natural resources and greenhouse gas emissions. It covers energy efficiency, sustainable site planning, material and resource conservation through the use of renewable resources, indoor air quality, recycling, and reuse (US green building design). When constructing a building, using both renewable and nonrenewable materials can help preserve nonrenewable resources and achieve green building certification. Plastic bottles are regarded as a type of waste that can be utilized in the construction of building components like the wall, roof, and so forth. By employing this type of waste as the raw material, we can contribute to lowering the energy used in brick factories to bake the bricks; lowering the energy and CO<sub>2</sub> emissions by using less cement; and so forth<sup>34</sup>.

## 2.6.3: Plastic Architecture

Utilizing waste materials to create affordable, livable architecture that enhances the quality of life in areas where plastic waste is improperly managed. "Plastic Architecture" investigates a circular cycle architecture pertaining to recycled plastics. The project promotes recycling by creating new construction materials for a variety of applications using digital fabrication tools and open-source technologies like the Precious Plastic machines. The project's wider impact is aimed at citizens, who will be able to customize design outputs through both the material and design processes.

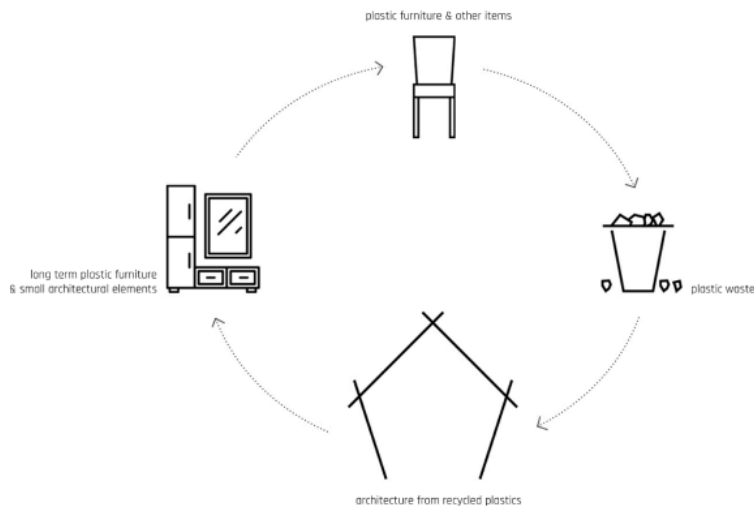
By raising awareness and disseminating knowledge, this protects the environment by aggregating plastics, which would otherwise put micro plastics at risk of degradation. This ultimately produces social and environmental capital within the framework of a circular economic model. The study of Plastic Emergency Architecture focuses on using recycled plastics to create simple, small-scale architectural components. Research investigates the benefits of materiality, the recycling process, and potential design scenarios while giving plastic waste its economic value back. This ultimately raises

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<sup>34</sup> P. Awoyera, and A. Adesina, 'Plastic Wastes to Construction Products: Status, Limitations and Future Perspective', *Case Studies in Construction Materials*, 12 (published online 2020), < <https://doi.org/10.1016/j.cscm.2020.e00330> > , E00330.

awareness among the public, the social and ecological classes, and improves the quality of life in areas where improper handling of plastic waste has occurred.<sup>35</sup>.

#### 2.6.4: Circular Economy

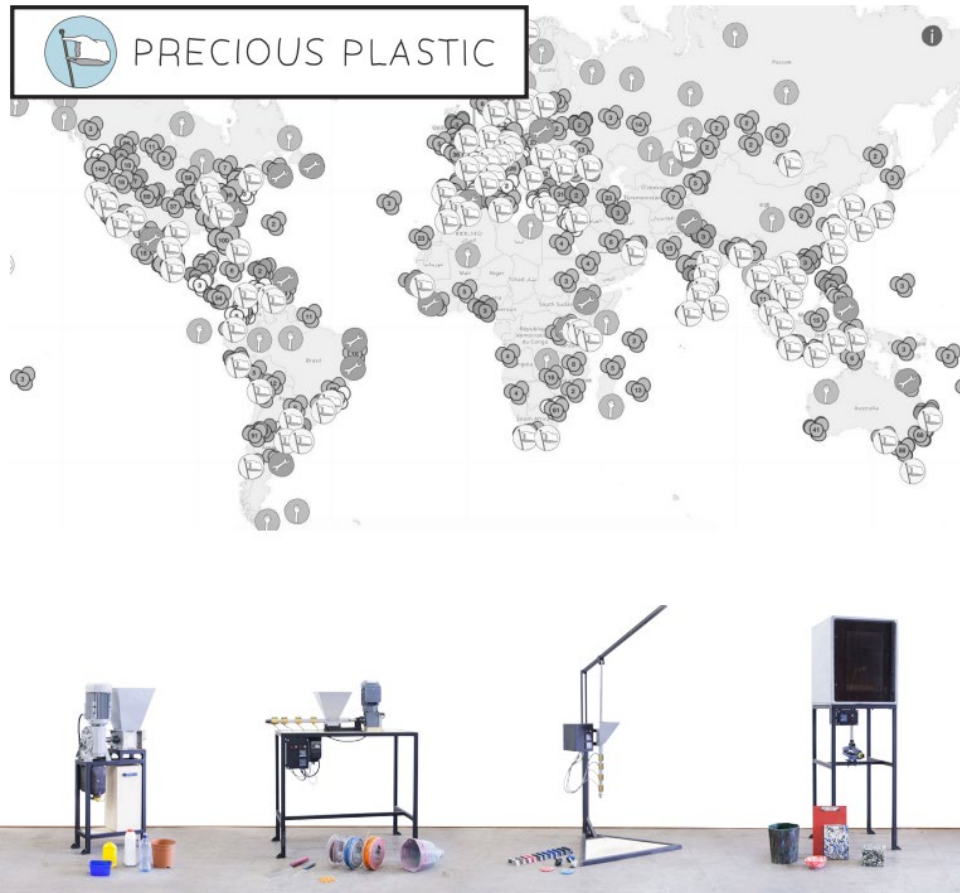


Circular economy model is a model, which allows the material flow to follow the rules of nature while serving the purpose and needs of all the species without creating any sort of waste. By distinguishing between technical and biological cycles, the model "is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times." Ellen MacArthur Foundation 2015. The transition from a linear economy model to a circular one, in other words - from “cradle to grave” to “cradle to cradle” - means to rethink the production and use of every item in order to let its purpose last as long as the lifespan of a material allows itself. It also seeks to stop the use of any finite resources<sup>36</sup>.

<sup>35</sup> S. Santos, 'Plastic Architecture: 12 Projects that Highlight the Potential of Polymers' [website] (2016), Archdaily, < <https://www.archdaily.com/783728/plastic-architecture-12-projects-that-highlight-the-potential-of-polymers> > .

<sup>36</sup> Ellen MacArthur Foundation, 'Plastics and the Circular Economy' [website] (n.d.), < <https://www.ellenmacarthurfoundation.org/plastics-and-the-circular-economy-deep-dive> > .

## 2.6.5: Precious Plastics



Precious Plastics is an initiative, according to them it's a "global community", which encourages collaborative thinking between people all around the World in order to recycle plastics in a small scale. In 2013, a Dutch designer Dave Hakkens came up with an idea to redesign industrial recycling machines into small, compact and relatively easy to build ones. Moreover, he published the drawings and other relevant information (such as tutorials, price lists and so on) online open source and let everyone who wants to make their own set. A set of 'plastic machines' created for small-scale DIY plastic recycling includes: - **Shredder** (cuts plastic waste into small pieces / flakes for further recycling process) - **Extrusion** (produces a line of molded plastic by pushing it out and heating along the way) - **Injection** (creates plastic elements inside their molds by warming up and pressing the plastic) - **Compression** (warms and slowly presses the plastic inside an oven)

After more than 5 years, the community has grown all around the World, counting more than 104,000 people who are investing their time to

contribute by building and upgrading the machines, the process and the purposes it all could serve

## 2.6.6: Plastics Recycling

The process of recycling consists of several steps.

First of all, the most difficult part is the **sorting of plastics**. Since there are different types of plastics, it is important to divide the waste according to them. (This will later on be crucial due to different chemical composition and melting temperatures.) Lately, due to global regulations on labeling every plastic item with the number of the type, the recycling of the most used 6 types of plastics became much more efficient.

Second step of plastic recycling is **cleaning**. This is a crucial, but, due to the high consumption of water, environmentally unfriendly part of the process.

Thirdly, the plastics are being **shredded**. Depending on the recyclers and the further use, sometime plastics are first melted to a consistent piece of material and then shredded or extruded as pellets.

Pre last step is **forming** the plastics. If plastics are being used for manufacturing plastic items, molds and mold making process is an essential part. Many applications of plastic recycling require an injection molding process; therefore, the material is melting while forming.

Although, if not, the last step of the process is **melting**. There are several ways which can efficiently increase the value of recycling. The important role is played by the technology advances. It is necessary to keep developing the process in order to make it environmentally friendly in each of the steps while maintaining the lowest possible price for recycling. Also, technical improvements and regulations are both essential for closing the value and economic gap between recycled plastics and a virgin plastic material. (Hopewell, Dvorak and Kosior, 2009)



## 2.6.7: Zero Waste Architecture

The goal of zero waste design is to reduce waste production by taking into account a product's or material's whole lifecycle. With a focus on environmental responsibility, resource efficiency, and sustainability, this strategy highlights the significance of developing a circular economy where waste is reduced and resources are used effectively.

Material selection, design for disassembly, modularity, adaptability, waste prevention, reuse and recycling, material recovery, and energy efficiency are important components and techniques of zero waste design.

Green roofs, rainwater collection, photovoltaic panels, recycled materials, flexible and adaptable spaces, and energy-efficient systems are examples of design principles and features.



Figure 68 Artist Impression of Zero waste urban design

Opportunities and Challenges for Zero Waste Design: Typical

Roadblocks and Possible Solutions for Zero Waste Design Implementation Include Cost, Regulation, Innovation, Collaboration, and Education.

Businesses can improve their reputation, obtain a competitive edge, and contribute to a more sustainable future by implementing zero waste design.

In order to address the global waste crisis and contribute to a more sustainable built environment, architects, interior designers, and construction companies must adopt zero waste design.

As we work toward a time when structures and areas are designed with zero waste in mind, we can lessen the effects of our waste crisis and create a world that is healthier and more resilient for coming generations.

## 2.6.8: Waste and Landfill Architecture

The architecture and land planning of waste management and disposal facilities, such as landfills, incinerators, recycling plants, etc., are the focus of the field of waste architecture.

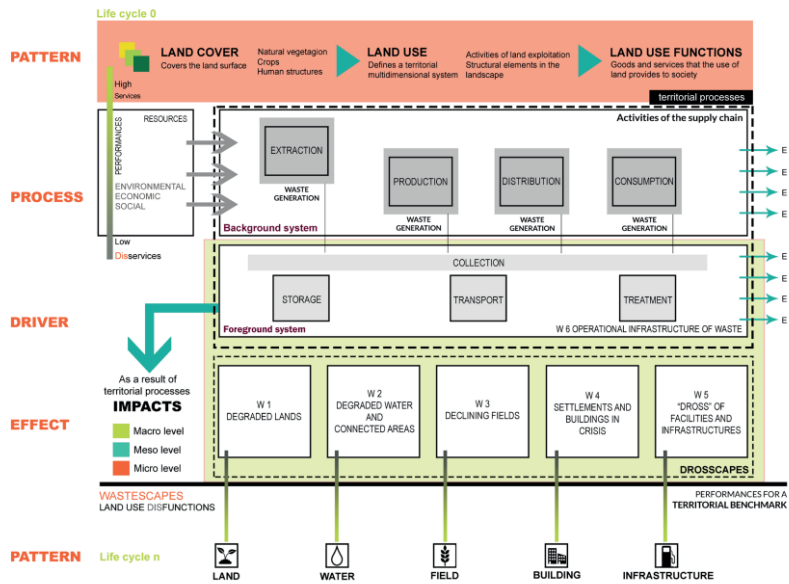


Figure 70: Waste scapes characterization model.

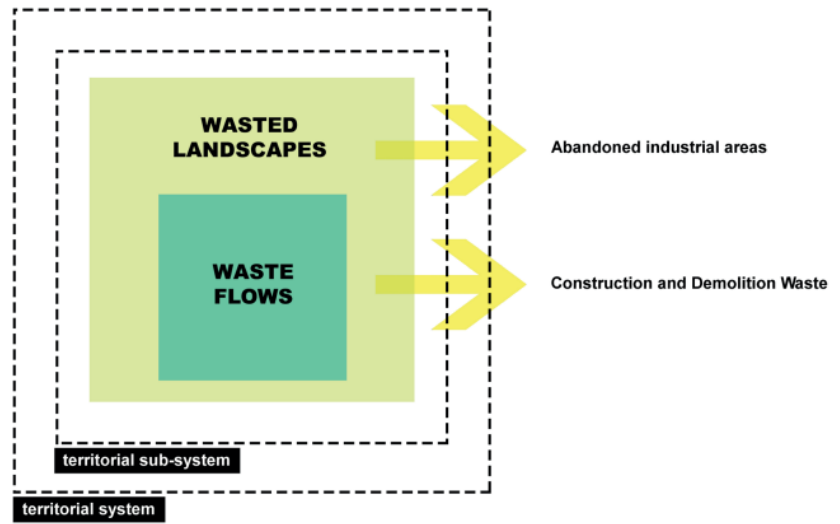


Figure 69: From wasted landscapes to waste flows.



## Principles:

- Integrating the waste management system with the territory and the landscape, rather than hiding or isolating it.
- Enhancing the legibility and recognizability of the waste management facilities, and raising environmental awareness among the public.
- Reusing and recycling the demolition material from existing buildings, rather than downcycling or disposing of it.
- Creating holding patterns, or indexed libraries of materials that can be reconfigured and adapted for future uses.
- Applying computational and optimization techniques to find the best fit and arrangement of irregular and misfit materials.

## Strategies:

- Scanning and indexing the demolition material into a digital catalogue that can be used for designing new constructions.
- Using graph theory, Hungarian method, and evolutionary algorithms to solve the irregular jigsaw puzzle problem posed by the demolition material.
- Visualizing and mapping the volume and distribution of demolition material in the city, and finding opportunities for infill and regeneration.



Figure 71 2019 Waste architecture Platform workshop

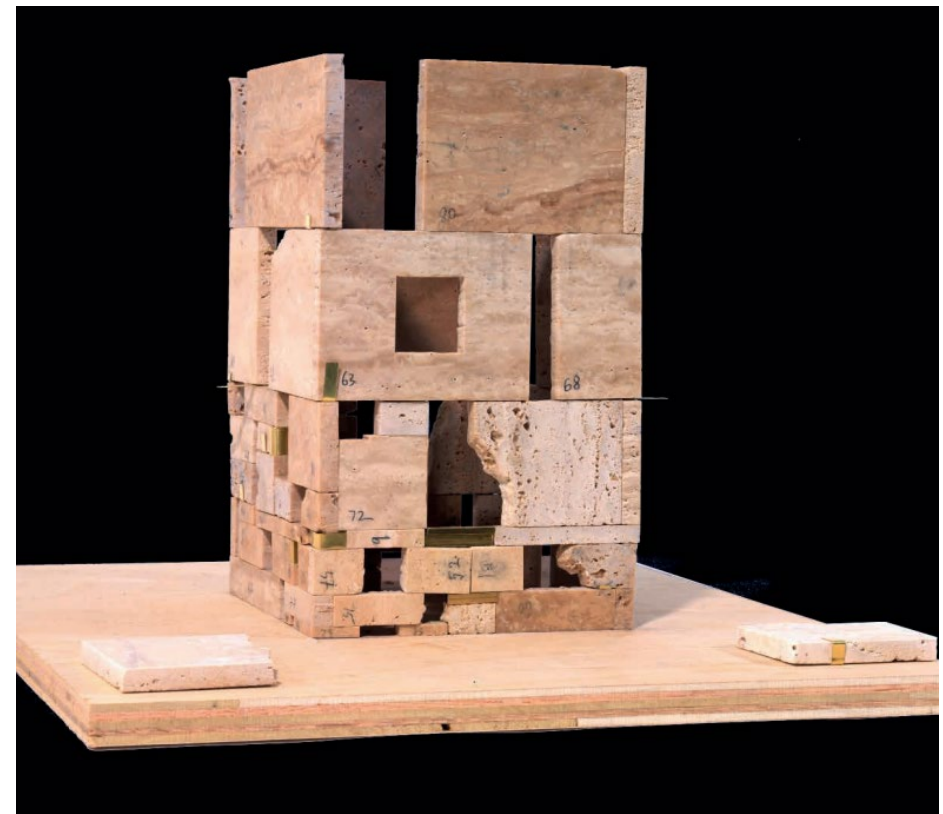


Figure 72 : Model created by arranging a collection of irregular rectangular elements

- Developing diaphragm wall sections that can provide structural stability and insulation for the recycled concrete assemblies.
- Testing and prototyping the computational methods in model and full-scale formats, and evaluating the performance and aesthetics of the recycled material.

### Challenges:

- The lack of recognition and regulation of the role of waste management facilities as primary urban infrastructures and essential public services.
- The technical and economic difficulties of reusing and recycling the demolition material, especially concrete, glass, and steel, which have different grades and qualities.
- The environmental and social impacts of transporting and disposing of the demolition material to out-of-state landfills, which generate greenhouse gas emissions and pollution.
- The fragility and poor insulation properties of concrete, which require additional reinforcement and protection for the recycled assemblies.
- The need for low-cost and reliable methods for identifying and grading the structural quality of the waste material, and for creating algorithms that can address the complexity and diversity of the demolition material.



*Figure 73 : It is possible to arrange demolition debris into "holding patterns." Maybe architects and urbanists can find temporary uses for this material instead of grinding it up and throwing it in the trash. By preserving patterns, future generations will be able to gather resource libraries for brand-new buildings.*

### Opportunities:

- The potential for creating innovative and sustainable architectural solutions that can reduce resource extraction and waste generation, and enhance the quality of the environment and the territory.
- The possibility of transforming degraded and abandoned areas, such as former landfills, into new functions and shapes, such as parks, buildings, landscapes, etc., that can benefit the community and the ecology.

- The opportunity of using artificial intelligence and machine learning to sort, classify, and organize the waste material, and to generate novel and optimal designs for the recycled assemblies.
- The chance of developing new aptitudes and skills for re-fitting and re-arranging misfit material, and creating eternal re-constructions that can learn from the past buildings.

The third edition of the International Workshop on Waste Architecture / Waste Management in Landscape and Urban Areas was held in 2019 by Arcoplan Associates. It was planned as a parallel event to the 17th International Waste Management and landfill Symposium in Sardinia. Using a multidisciplinary and collaborative approach, the design lab at the International Workshop on Waste Architecture 2019 sought to investigate the possibilities of repurposing landfills into new uses and forms. The main conclusions of the design lab were:

- Landfill redevelopment can be more successful if planned during the active phase of the landfill, allowing more flexibility and creativity in shaping the waste mass and integrating it with the surrounding landscape.
- Landfill redevelopment can provide innovative and diverse functions, such as archaeological-industrial parks, themed itineraries, educational centers, sports facilities, and energy crops, depending on the site characteristics, the stakeholders' needs, and the environmental benefits.
- Landfill redevelopment can be an opportunity to raise awareness and educate the public about waste issues, circular economy, and sustainability, by creating attractive and accessible spaces that showcase the waste history and potential of the site.
- Landfill redevelopment can be an exportable model for similar contexts, especially in developing countries, where waste management is a major challenge and landfills are often neglected or abandoned.



Figure 74 Waste architecture Platform workshop

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## 2.7: SUMMARY OF THE LITERATURE

This review makes the following major conclusions. Building from plastic waste is a multifaceted and multidimensional phenomenon that involves various environmental, social, economic, technical, and political aspects.

It can offer several benefits, such as reducing the environmental impacts of construction and demolition waste, creating employment opportunities and income generation for the informal sector and marginalized groups, providing affordable and durable housing solutions for low-income households and slum dwellers, reducing the construction costs and increasing the profitability of building projects, stimulating innovation and entrepreneurship in the construction industry, and creating new markets and value chains for waste materials.

Building from plastic waste also faces several challenges and limitations, such as technical difficulties and uncertainties, regulatory obstacles and gaps, social resistance and stigma, economic risks and constraints.

Its implementation is influenced by different factors, such as the availability and quality of waste materials, the demand and preferences of users and customers, the regulations and policies of governments and authorities, the costs and benefits of production and consumption, and the innovation and creativity of designers and entrepreneurs.

It varies across different African countries and regions, such as South Africa, Nigeria, Ghana, Ethiopia, Rwanda, and Kenya. There are significant variations and disparities in the extent, scope, quality, and impact of building from solid waste across different African contexts. There are also some commonalities and diversities, convergences and divergences, trends and patterns among different African contexts.

Building from plastic waste relates to other aspects of sustainable development in Kenya, such as poverty reduction, urbanization, climate change adaptation and mitigation, circular economy, green growth, and innovation. Building from solid waste can contribute to or complement other development goals and initiatives in Kenya.

## 2.8: THEORETICAL AND CONCEPTUAL AND FRAMEWORK

### 2.8.1: THEORETICAL FRAMEWORK

#### THE WASTE MANAGEMENT HIERARCHY AND THE CIRCULAR ECONOMY

These are two frameworks for sustainable solid waste management. They rank the different options for waste management according to their environmental impact and resource efficiency, and how they aim to reduce waste generation and promote waste reuse and recycling. The frameworks discuss how waste can be considered as a secondary material that can be used for new applications, such as building products, especially plastic waste, which is one of the most abundant and problematic types of waste in the world<sup>37</sup>.

#### Waste Management Hierarchy

This approach ranks the different options for waste management according to their environmental impact and resource efficiency, from the least preferable (landfill) to the most preferable (reduce). It also distinguishes between reuse and recycling, which are two ways of using waste as a secondary material for new products or applications. The text shows how the waste management hierarchy approach is presented in a pyramidal form in various regulations and policies, but also acknowledges that some options (such as incineration) are controversial and may vary depending on the context. The text argues that the waste management hierarchy approach is based on the conception of waste as a resource rather than as a public health problem, and that it aims to minimize waste generation and maximize waste utilization.

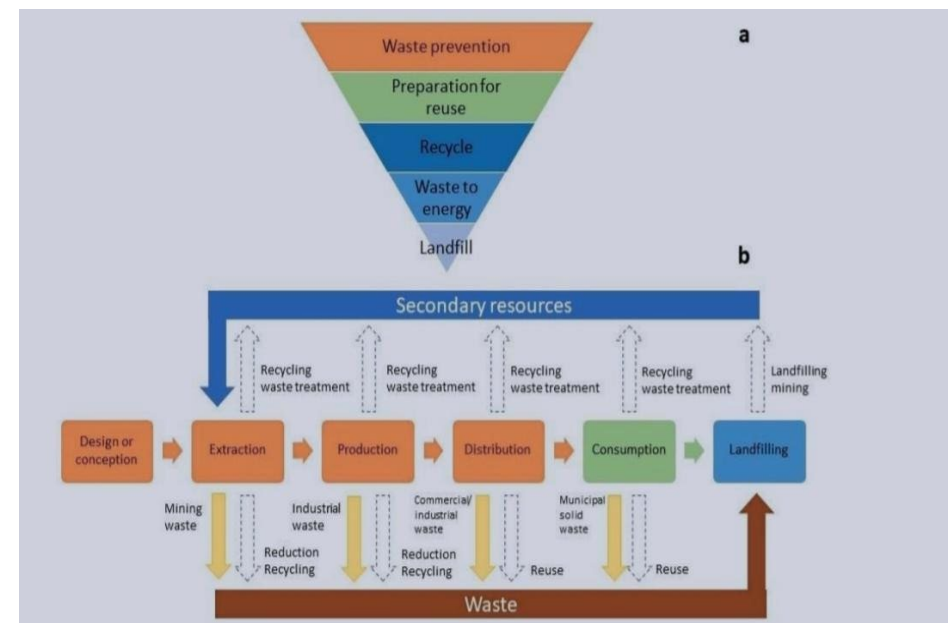


Figure 75 Figure 1. (a) Waste hierarchy principle according to the Waste and Climate Change Strategy Framework of the United Nations Environmental Programme [14]; (b) waste as a secondary resource (adapted from Chang and Pires [1]). In both diagrams, pre-use, use, and post-use phases appear in orange, green, and blue, respectively.

<sup>37</sup> L. Traven, 'Circular Economy and the Waste Management Hierarchy: Friends or Foes of Sustainable Economic Growth? a Critical Appraisal Illustrated by the Case of the Republic of Croatia', *Waste Management & Research*, 37/1 (published online 2019), < <https://doi.org/10.1177/0734242X18818985> > , 1-2.

## Circular Economy Approach

The circular economy approach is a theoretical framework that proposes a more sustainable and efficient way of managing waste. It is based on the 3Rs rule, which consists of three main actions: reduce, reuse, and recycle. These actions are ordered according to their environmental impact and resource efficiency, with reduce being the most preferable and recycle being the least. The circular economy approach aims to minimize waste generation and maximize waste utilization by designing products that can be easily reused or recycled, and by finding new applications for waste as a secondary material. The circular economy approach is inspired by natural biogeochemical cycles, which create closed material loops that use less energy and produce less pollution and emissions. The circular economy approach also recognizes other waste management options, such as refuse, repair, refurbish, remanufacture, repurpose, recover energy, and re-mine, which are collectively known as the 10Rs.

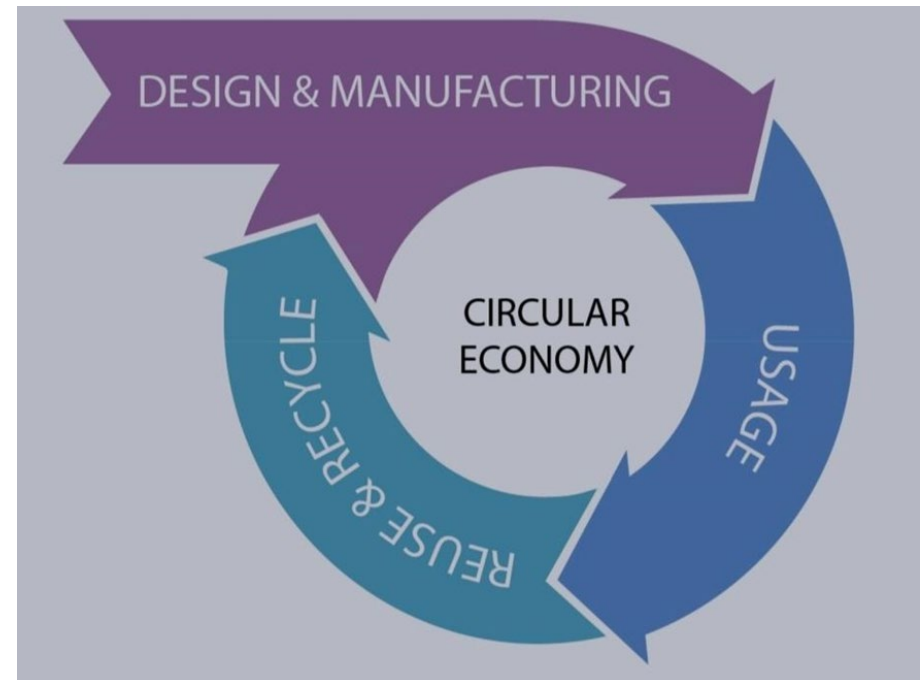


Figure 76 Circular Economy flow chart. Source Plastindia 2018

## SUSTAINABLE DEVELOPMENT

The research is framed within the same aspects as the 2030 Agenda for Sustainable Development. The agenda, published in 2015, defines a collection of 17 Sustainable Development Goals and 169 targets and is set by the Heads of State and Government and High Representatives during a meeting at United Nations Headquarters in New York. It targets the current global issues in order to improve the situation within 15 years' time (United Nations, 2015). The research on "Plastic Architecture" takes into account a number of goals, including No Poverty, Zero Hunger, Good

# SUSTAINABLE DEVELOPMENT GOALS



Health and Well-Being, Quality Education, Clean Water and Sanitation, Decent Work and Economic Growth, Sustainable Cities and Communities, Responsible Consumption and Production, Climate Action, Life Below Water, and Partnership for the Goals (fig.01). The agenda outlines the shared values and commitments for the next fifteen years in addition to goals and targets. Specifically, the 28th commitment establishes the parameters for this study's framework.

Figure 77 Sustainable Development Goals (United Nations, 2015) Colors identifies the ones which are aligned with the research Plastic Architecture

## CONCEPTUAL FRAMEWORK

The conceptual framework that guides my research is based on the following diagram below

It shows how **building from plastic waste** can be understood as a **process** that involves four main stages: **(1) waste collection; (2) waste processing; (3) waste manufacturing; (4) waste utilization**. Each stage involves different actors, activities, inputs, outputs, outcomes, impacts, opportunities, and challenges. The conceptual framework also shows how building from solid waste can be influenced by different factors at different levels: **(1) individual; (2) organizational; (3) institutional; (4) contextual**. Each level involves different aspects that shape building from solid waste: **(1) motivation; (2) capacity; (3) regulation; (4) environment**.

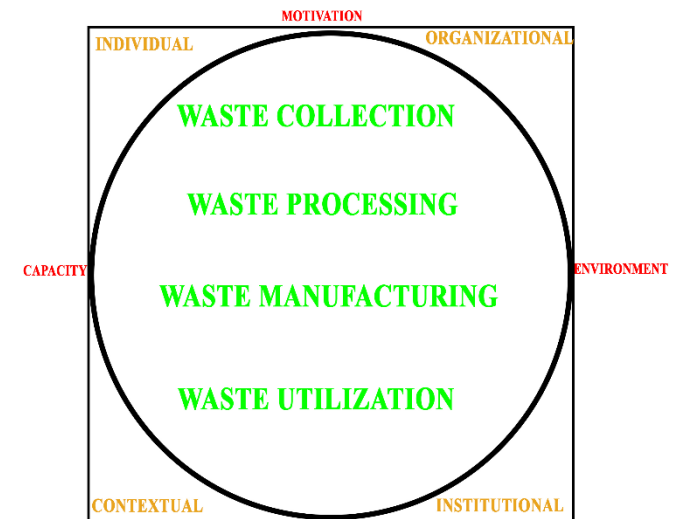


Figure 78 Conceptual framework diagram

## GAPS AND OPPORTUNITIES FOR FUTURE RESEARCH

1. The **lack of documentation**, data and evidence on the feasibility, performance and impact of using plastic waste as a construction material in the local context of Kenya. This gap can be filled by conducting empirical studies, such as case studies, interviews, surveys, and experiments, to collect and analyze data from various sources and perspectives.
2. The industry of building with waste is not established or regulated in Kenya hence **a need for developing and implementing a framework and a roadmap for using plastic waste as a construction material, based on the principles of circular economy and waste management**. This framework and roadmap can provide guidance and recommendations for the design, production, regulation, and monitoring of plastic waste-based construction material, as well as for the creation and expansion of the market and the value chain for this material.
3. The novelty of the concept of using plastic waste as a construction material in Kenya. This **novelty can be exploited by exploring and experimenting with different types of plastic waste, different methods of processing and transforming plastic waste, and different applications and benefits of using plastic waste** as a construction material. This exploration and experimentation can lead to the development of innovative and sustainable solutions for the plastic waste crisis and the housing shortage in Kenya and other similar contexts. Based on the parameters stated in the literature review, some of the things that can be found out in the **field research are**:
  - The technical, economic, social and environmental aspects of selected projects and initiatives that use plastic waste as a building material in Kenya and other similar contexts, such as the types, properties, performance, and impact of plastic waste-based construction material, the methods and costs of production and implementation, emerging technologies, the challenges and opportunities for adoption and acceptance, and the benefits and drawbacks for the environment and the society.
  - The perspectives, experiences, and expectations of key stakeholders, such as policy makers, practitioners, researchers, and communities, involved or interested in building from plastic waste in Kenya, such as their motivations, challenges, and opportunities for using plastic waste as a construction material, the factors that influence their decision-making and behavior, and their needs, preferences, and perceptions of plastic waste buildings.
  - The preferences, attitudes and perceptions of potential users and beneficiaries of plastic waste buildings in Kenya, such as their awareness and knowledge of plastic waste as a construction material, their satisfaction and dissatisfaction with plastic waste buildings, their willingness and readiness to use and live-in plastic waste buildings, and their demographic, socio-economic, and geographic characteristics.

## CHAPTER 03:

# PRECEDENT STUDIES

*This chapter analyzes and learns from existing cases or situations that are relevant to the topic of using plastic waste as a construction material. It compares and contrasts different approaches, methods, and outcomes of similar or related studies. It also demonstrates knowledge and understanding of the existing literature and the context of the research. It also provides a rationale and justification for the research design, methodology, and analysis.*

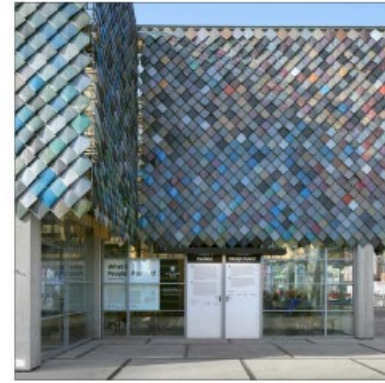


Figure 79 Construction with plastic bottles in Nigeria, Source BBC 2008

There are some applications of recycled plastics within the field of architecture. Considering the fact that a building lasts from dozen to hundreds of years, plastic might be a beneficial addition to the constructions. Recycled plastics have already been utilized up until this point as substitutes for bricks, fences, roofing tiles, structural lumber, and other materials. It has also shown to be a great addition during the concrete-making process, strengthening the material structurally and making it ideal for sidewalks, driveways, and other applications. (Calovini, 2018) Technological advancements and global concerns about the issue have prompted architects worldwide to investigate the potential and uses of recycled plastics in architecture in recent years. It has been used in many pavilions and small architecture object with a direct use - for example houses from plastic bottles and boxes, inflatable pavilions from plastic bags, or indirect use - as cladding, Lego type bricks or even 3D filament for robotically fabricated structure



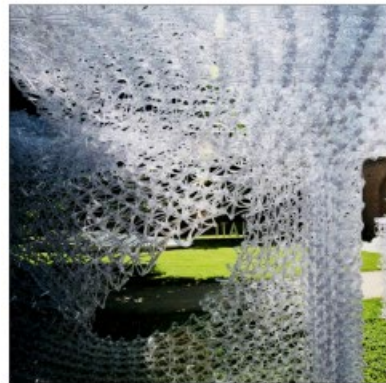
The Cola-Bow Installation by Penda, 2013



People's pavilion by Bureau SLA and Overtheders W, 2017



Origami Pavilion by IU School of Art, Architecture + Design in Bloomington, 2017



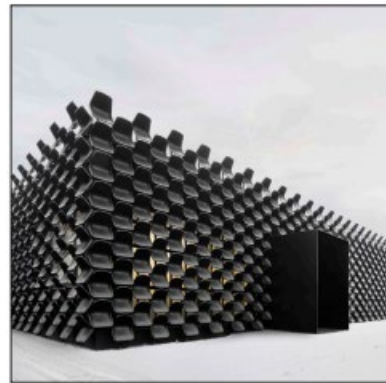
Cloud Village Chinese pavilion @ Venice Biennale 2018



Pretty Plastic Plant by Bureau SLA and Overtheders W, 2016



Head in the Clouds by STUDIOKCA, 2013



Gallery of Furniture by CHYBIK + KRISTOF, 2016



House from Recycled Plastic Bricks by Conceptas Plasticas, 2017



A wall from 1,500 baskets by Hyunje Joo, 2017



I-COND by Bianchimajer and Anna Merzi,  
2019



PET pavilion by Project.DWG and LOOS.FM,  
2014



Casa Umbrella by Kengo Kuma,  
2013

Figure 80 Applications of plastic in Architecture at a glance. Source Plastindia 2019

### 3.1: SELECTION CRITERIA AND METHODOLOGY

The selection criteria and parameters analyzed for these precedent studies of buildings made of plastic waste include the following factors:

- The type and source of plastic waste used (e.g., PET bottles, HDPE bags, LDPE films, etc.)
- The method and process of recycling plastic waste (e.g., mechanical, chemical, thermal, etc.)
- The design and construction of the building (e.g., shape, size, structure, function, etc.)
- The performance and durability of the building (e.g., strength, thermal insulation, fire resistance, etc.)
- The environmental and social impacts of the building (e.g., greenhouse gas emissions, waste reduction, community involvement, etc.)

### 3.2: INTERNATIONAL PRECEDENTS PLASTIC BOTTLE VILLAGE, PANAMA



The **type and source** of plastic waste used: PET bottles, collected from various sources, including local residents and businesses.

The **method and process** of recycling plastic waste: Mechanical recycling, filling the bottles with sand and binding them with wire or string.

The **design and construction** of the building: Various types of buildings, such as houses, hotels, hostels, and museums, made of bottle bricks. The bottle bricks are arranged in different patterns and shapes, creating colorful and artistic facades. The buildings also use other recycled materials, such as metal, wood, and tires.



The **performance and durability** of the building: The bottle bricks are strong, lightweight, and transparent. They also provide natural light and ventilation, as well as aesthetic appeal. The buildings are designed to be low-cost, low-maintenance, and adaptable to different contexts and needs<sup>38</sup>.



The **environmental and social impacts** of the building: The buildings provide sustainable and affordable housing and tourism for the island, especially in places with limited access to conventional building materials. The buildings also reduce plastic waste and environmental pollution, while empowering the local residents to participate in the design and construction process. Additionally, he has listed a number of uses for them, including home insulation, quick temporary shelters following emergencies, farm animal buildings, swimming pools, barns, roads, and more.



<sup>38</sup> Designboom, 'Robert Bezeau Builds Entire Village Out of Plastic Bottles in Panama' [website] (2019), Designboom | Architecture & Design Magazine, < <https://www.designboom.com/architecture/robert-bezeau-plastic-bottle-village-panama-04-24-2019/> > .

## PET PAVILLION IN ENSCHEDE, NETHERLANDS.



The **type and source of plastic waste** used: PET bottles, collected from local households and businesses.

The **method and process of recycling plastic waste**: Mechanical recycling, shredding the bottles into flakes and melting them into transparent corrugated sheets.



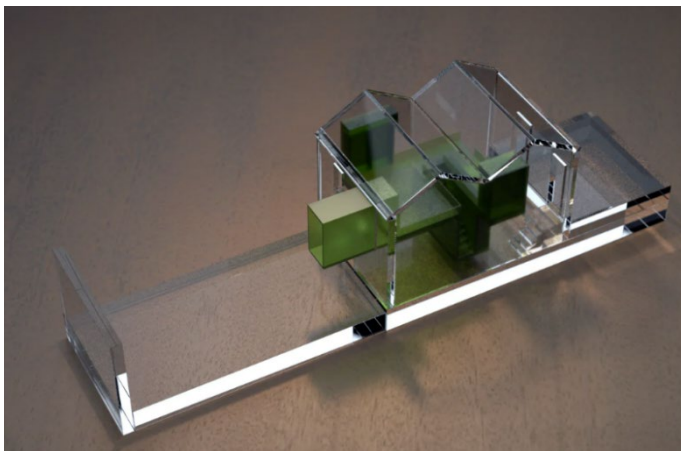
The **design and construction of the building**: A temporary pavilion inspired by the Farnsworth House, consisting of two steel slabs supported by a steel frame, wrapped in plastic sheets that hold over 40,000 bottles. The pavilion also has a webbing of plastic tubes that create a dynamic spatial experience.

The **performance and durability of the building**: The plastic sheets provide natural light and ventilation, as well as acoustic insulation. The plastic tubes create a playful and colorful atmosphere. The pavilion is designed to be easily dismantled and reused or recycled.



The **environmental and social impacts** of the building: The pavilion aims to raise awareness about plastic waste and recycling, as well as to provide a public space for cultural and social activities. The pavilion also involves the local community in the collection and processing of plastic waste.

### PLASTIC HOUSE IN DUBLIN, IRELAND



The **type and source of plastic waste** used: Polycarbonate sheets, salvaged from a greenhouse demolition.

The **method and process of recycling plastic waste**: Mechanical recycling, cutting the sheets into panels and fixing them to a timber frame.

The **design and construction of the building**: A renovation and extension of an existing house, using plastic panels as cladding and roofing. The plastic panels create a translucent skin that allows natural light and views, while also providing privacy and insulation.

The **performance and durability of the building**: The plastic panels are lightweight, flexible, and resistant to weather and fire. They also reduce the energy consumption of the house by creating a thermal buffer and reducing the need for artificial lighting.

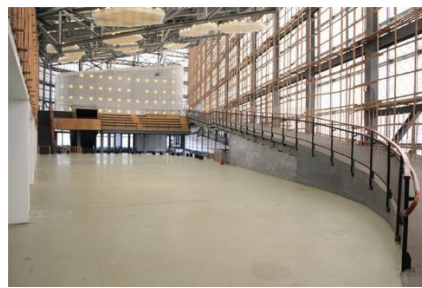
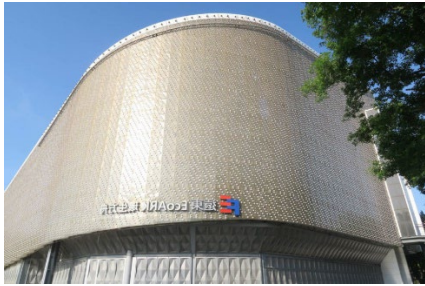


The **environmental and social impacts** of the building: The plastic panels give the house a distinctive and contemporary appearance, while also reusing a waste material that would otherwise end up in a landfill. The plastic panels also create a comfortable and bright living environment for the occupants.



## ECOARK IN TAIPEI, TAIWAN

The kind and origin of the plastic waste utilized: It is the first nine-story building in the world constructed entirely of Polli-Brick™, a building material invented by MINIWIZ and composed of 100% recycled PET bottles from a variety of sources, such as beverage manufacturers and recycling companies. It is now a public museum and served as the centerpiece of the 2010 Taipei International Flora Exposition.



The **method and process of recycling plastic waste**: Mechanical recycling, crushing the bottles into flakes and molding them into interlocking bricks, called POLLI-Bricks.

The **design and construction of the building**: A large-scale pavilion, composed of three sections: a curved wall, a honeycomb-shaped hall, and a spiral-shaped tower. The pavilion is made of over 1.5 million pet bottles converted to 300 thousand Polli bricks, which are assembled without any glue or nails, using a snap-fit mechanism. The 130-meter-long structure is completely deconstructable — it can be taken apart and reassembled at another location, kind of like a giant LEGO building.



The **performance and durability of the building**: The POLLI-Bricks are strong, lightweight, and transparent. They also have air pockets that provide thermal and acoustic insulation, as well as solar cells that generate electricity. The pavilion is designed to be modular, movable, and adaptable to different climates and locations. The eco-cred the building was engineered to withstand large earthquakes and typhoons

The **environmental and social impacts of the building**: The pavilion showcases the potential of plastic waste as a building material, as well as the benefits of circular economy and green design. The pavilion also serves as a venue for exhibitions, concerts, and other events, attracting millions of visitors and promoting environmental awareness and education.

### 3.3: REGIONAL PRECEDENTS PLASTIC BOTTLE VILLAGE IN YELWA, NIGERIA.



The **type and source** of plastic waste used: PET bottles, collected from local households and businesses.

The **method and process** of recycling plastic waste: Mechanical recycling, filling the bottles with sand and binding them with mud. *"Compacted sand inside a bottle is nearly 20 times stronger than bricks, we are even intending to build a three-story building."* Yahaya Ahmed of Nigeria's Development Association for Renewable Energies.



The **design and construction** of the building: Various types of buildings, such as houses, classrooms, health centers, and latrines, made of bottle bricks. The bottle bricks are stacked one on top of the other and secured with mud on their sides. The structures are constructed in the traditional northern Nigerian round architectural form. With a bedroom, living room, bathroom, kitchen, and toilet, each house is thought to use 7,800 plastic bottles<sup>39</sup>.



Figure 81 Children making money filling bottles may one day be able to attend a school to be built on the estate



Figure 82 Bottles from hotels and restaurants

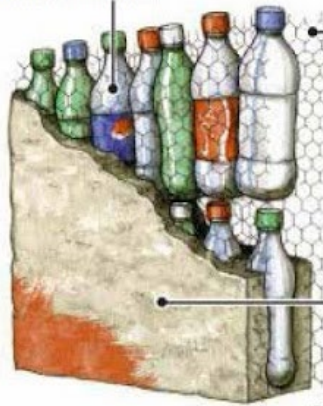
<sup>39</sup> S. Olukoya, 'Nigeria's Plastic Bottle House' [website] (2011), Bbc News, < <https://www.bbc.com/news/world-africa-14722179> > .

The **performance and durability** of the building: The bottle bricks are waterproof, fire resistant, and earthquake-resistant. They also have thermal and acoustic insulation properties. The buildings are easy to assemble and disassemble, requiring no skilled labor or heavy machinery. Bullet proof hence secure considering the war rates in North Nigeria.

### BUILDING A BOTTLE WALL

#### Bottles

Community members stuff the plastic bottles with plastic bags and other insulating trash. More plastic bags fill in the gaps between the bottles.



#### Chicken Wire

The bottles are bound between layers of chicken wire, which are attached to a metal frame.

#### Cement

Up to three layers of cement mixed with sand are applied to the outside of the bottles, with paint adding the finishing touch.

Image Credit: Eric Baker/The Oregonian



The **environmental and social impacts** of the building: The buildings provide sustainable and affordable infrastructure for rural communities, especially in areas with limited access to conventional building materials. The buildings also reduce plastic waste and environmental pollution, while creating jobs and income for local workers. It costs 1/3 price than conventional concrete and brick.

### KUBIK LOW-CARBON BUILDINGS IN VARIOUS LOCATIONS, ETHIOPIA.



100%  
Plastic  
Waste



5x Less CO2  
Needed



40%  
Cheaper

The **type and source** of plastic waste used: Various types of plastic waste, such as PET bottles, HDPE bags, LDPE films, etc., collected from local communities and waste pickers.

The **method and process** of recycling plastic waste: Mechanical recycling, shredding the plastic waste into flakes and extruding them into Lego-like blocks, called Kubik Bricks.

The **design and construction** of the building:

Various types of buildings, such as residential,

commercial, and public facilities, made of Kubik Bricks. The Kubik Bricks are stacked and interlocked, forming walls, roofs, and floors. The buildings can be customized according to the needs and preferences of the users.



Figure 83 Kubik school. Source Kubik website 2019

The **performance and durability** of the building: The Kubik Bricks are waterproof, fireproof, and earthquake-resistant. They also have thermal and acoustic insulation properties. The buildings are easy to assemble and disassemble, requiring no skilled labor or heavy machinery.

The **environmental and social impacts** of the building: The buildings provide low-carbon and affordable housing and education for low-income and vulnerable populations, such as refugees, displaced people, and rural communities. The buildings also reduce plastic waste and greenhouse gas emissions, while creating jobs and income for waste pickers and local workers



Figure 84 Gjenge makers pavers in a school. Source Gjengemakers website 2021

### 3.4: LOCAL PRECEDENTS GJENGE MAKERS IN NAIROBI, KENYA

The Gjenge Makers in Kenya, founded in 2017, is a social enterprise that produces paving bricks made of plastic waste and sand. The bricks are stronger, lighter, and cheaper than conventional bricks, and they help to solve the problem of plastic waste disposal and create employment opportunities.

The **type and source** of plastic waste used: Various types of plastic waste, such as PET bottles, HDPE bags, LDPE films, etc., collected from local communities and waste pickers.

The **method and process** of recycling plastic waste: Mechanical recycling, shredding the plastic waste into flakes and molding them into interlocking bricks, called Gjenge Bricks.

The **design and construction** of the building: Various types of buildings, such as pavements, sidewalks, and driveways, made of Gjenge Bricks.

### 3.5: PRECEDENT STUDY ANALYSIS AND COMPARISON

Sr. No.	Factors and Considerations	Plastic Bottle Wall	Brick Wall
1	Execution time and speed	15% faster than brick wall	120 m <sup>2</sup> per day with 5 persons working
2	Material costs	Lower than brick wall, as plastic bottles are waste materials	Higher than plastic bottle wall, as bricks are conventional materials
3	Transportation and equipment costs	Lower than brick wall, as plastic bottles are lighter and easier to transport	Higher than plastic bottle wall, as bricks are heavier and require more vehicles and equipment
4	Execution costs	Lower than brick wall, as plastic bottles require less skilled labor and less mortar	Higher than plastic bottle wall, as bricks require more skilled labor and more mortar
5	Strength and load capacity	Comparable to brick wall, as plastic bottles filled with sand are strong and stable	Comparable to plastic bottle wall, as bricks are strong and stable
6	Earthquake resistance	Higher than brick wall, as plastic bottles are flexible and can absorb shocks	Lower than plastic bottle wall, as bricks are rigid and can crack under pressure

<b>Sr. No.</b>	<b>Factors and Considerations</b>	<b>Plastic Bottle Wall</b>	<b>Brick Wall</b>
7	Fire resistance	Higher than brick wall, as plastic bottles are non-combustible and can withstand high temperatures	Lower than plastic bottle wall, as bricks are combustible and can collapse under high temperatures
8	Flexibility of work	Higher than brick wall, as plastic bottles can be arranged in different shapes and sizes	Lower than plastic bottle wall, as bricks have a fixed shape and size
9	Environmental impact	Positive, as plastic bottles reduce plastic waste and environmental pollution	Negative, as bricks increase greenhouse gas emissions and resource consumption



Figure 85 :Crushed plastic pellets. Source Author 2023

## CHAPTER 04:

# RESEARCH METHODS

*This chapter describes the research design, data collection methods, data analysis methods, and ethical considerations of the study. It explains the rationale and justification for choosing a mixed-methods approach, which combines quantitative and qualitative data. It also details the instruments, procedures, and techniques used for data collection and analysis, such as surveys, interviews, observations, and content analysis]. It also discusses the validity, reliability, and limitations of the methods and the data.*

## 4.1: RESEARCH DESIGN AND APPROACH

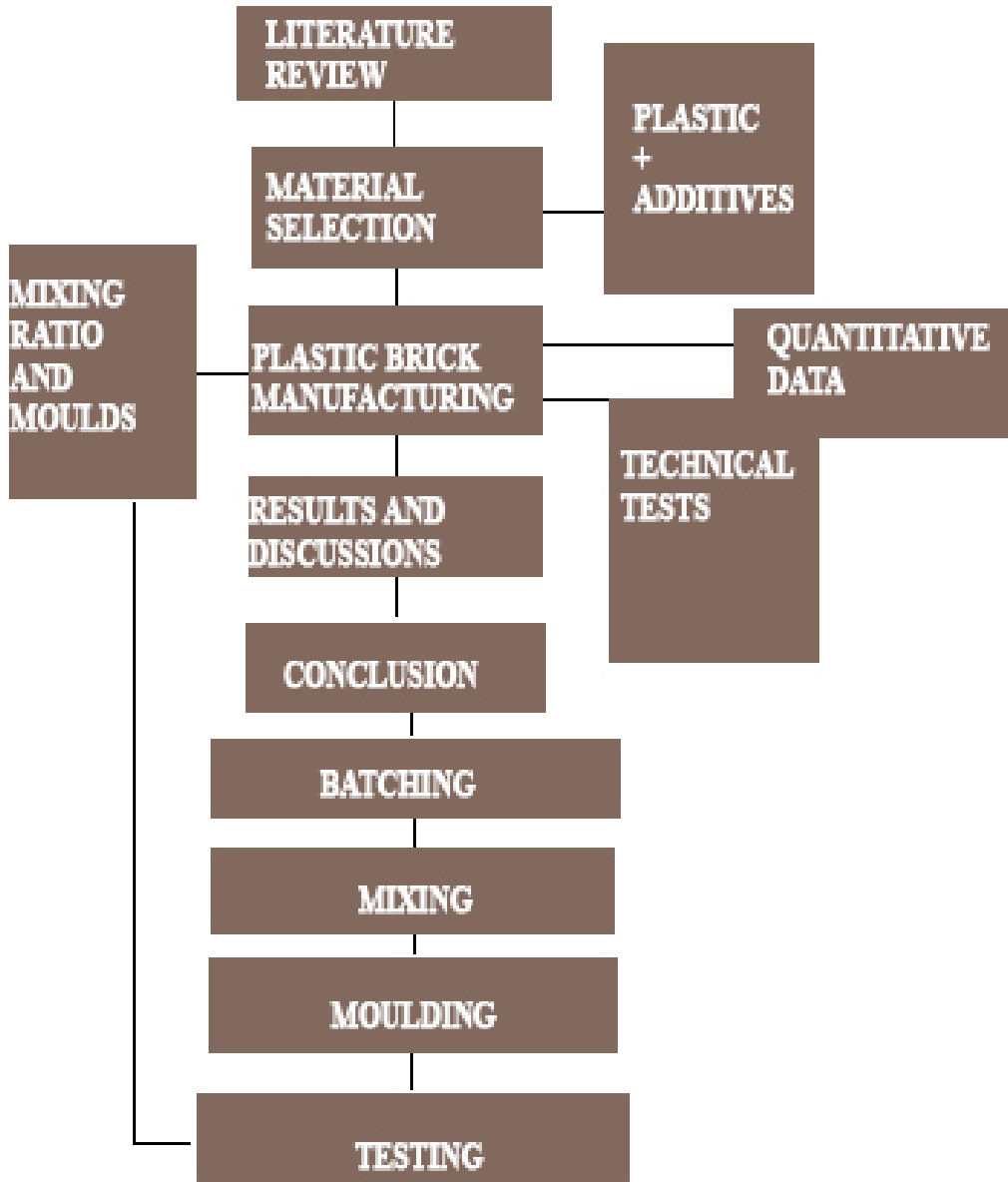


Figure 86 Methodology chart

The research design is both exploratory and quasi-experimental design that involves testing the performance of building materials made from plastic waste. The paper shall also explore the qualitative aspects of using the plastic waste material such as perceptions

**Technical parameters:** These are the parameters that relate to the physical and mechanical properties of the plastic waste products, such as density, compressive strength, water absorption, and thermal conductivity. These parameters can be measured using standard laboratory tests and instruments, such as a scale, a compression machine, a water tank, and a thermal conductivity meter. These parameters can be analyzed using statistical methods, such as mean, standard deviation, t-test, ANOVA, etc. to compare the performance of different types of plastic waste products and to evaluate their suitability for different applications

**Non-technical parameters:** These are the parameters that relate to the opinions and perceptions of the stakeholders involved in the plastic waste construction process, such as the workers, the managers, the customers, and the community members. These parameters can be measured using qualitative methods, such as interviews, surveys, focus groups, observations, etc. to collect the views and experiences of the stakeholders. These parameters can be analyzed using thematic analysis, content analysis, discourse analysis, etc. to identify the main themes, patterns, and issues that emerge from the data.

<b>Parameter</b>	<b>Type</b>	<b>Measurement</b>	<b>Analysis</b>
Density	Technical	Scale	Mean, standard deviation, t-test, ANOVA
Compressive strength	Technical	Compression machine	Mean, standard deviation, t-test, ANOVA
Water absorption	Technical	Water tank	Mean, standard deviation, t-test, ANOVA
Thermal conductivity	Technical	Thermal conductivity meter	Mean, standard deviation, t-test, ANOVA
Opinions	Non-technical	Interviews, surveys, focus groups	Thematic analysis, content analysis, discourse analysis
Perceptions	Non-technical	Interviews, surveys, focus groups	Thematic analysis, content analysis, discourse analysis

#### 4.2: DATA COLLECTION METHODS AND TOOLS

The data collection methods and tools for the quantitative data are observation and testing. Observation is used to record the characteristics and **conditions of the plastic waste construction sites, such as the size, layout, equipment, safety, and cleanliness**. Testing is used to measure the physical and mechanical properties of the plastic waste products, using various tools and instruments, such as a digital scale, a vernier caliper, a compression testing machine, a water bath, and a thermal conductivity meter.

The data collection methods and tools for the qualitative data are interviews and a narrative design approach. Interviews are used to elicit the stories, opinions, attitudes, perceptions, and emotions of the stakeholders, using a semi-structured interview guide with open-ended questions

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### 4.3: DATA ANALYSIS METHODS AND TOOLS

The data analysis methods and tools for the quantitative data are descriptive and inferential statistics. Descriptive statistics are used to summarize, compare, and present the data, using measures such as frequencies, percentages, means, standard deviations, and ranges. Inferential statistics are used to test the data and identify the relationships among the variables, using tests such as t-test, ANOVA, and correlation. The data analysis tools include Microsoft Excel and SPSS software.

The data analysis methods and tools for the qualitative data are thematic and narrative analysis. Thematic analysis is used to code, categorize, and interpret the data, using a deductive and inductive approach to identify the themes, patterns, and meanings that emerge from the data. Narrative analysis is used to review, re-tell, and re-construct the data, using a chronological and logical approach to understand the structure, content, and context of the stories. The data analysis tools include NVivo and Atlas. software.

### 4.4: ETHICAL CONSIDERATIONS AND VALIDITY

The ethical considerations for the research include obtaining the informed consent, ensuring the voluntary participation, and protecting the confidentiality and anonymity of the participants. The research also respects the dignity, rights, and interests of the participants, and avoids any harm, deception, or coercion. The research also acknowledges the sources of information and avoids any plagiarism, fabrication, or falsification of data.

The validity of the research includes ensuring the accuracy, reliability, and generalizability of the quantitative data, and the authenticity, credibility, and transferability of the qualitative data. The research also uses various strategies to enhance the validity of the data and the findings, such as triangulation, member checking, peer review, and reflexivity.

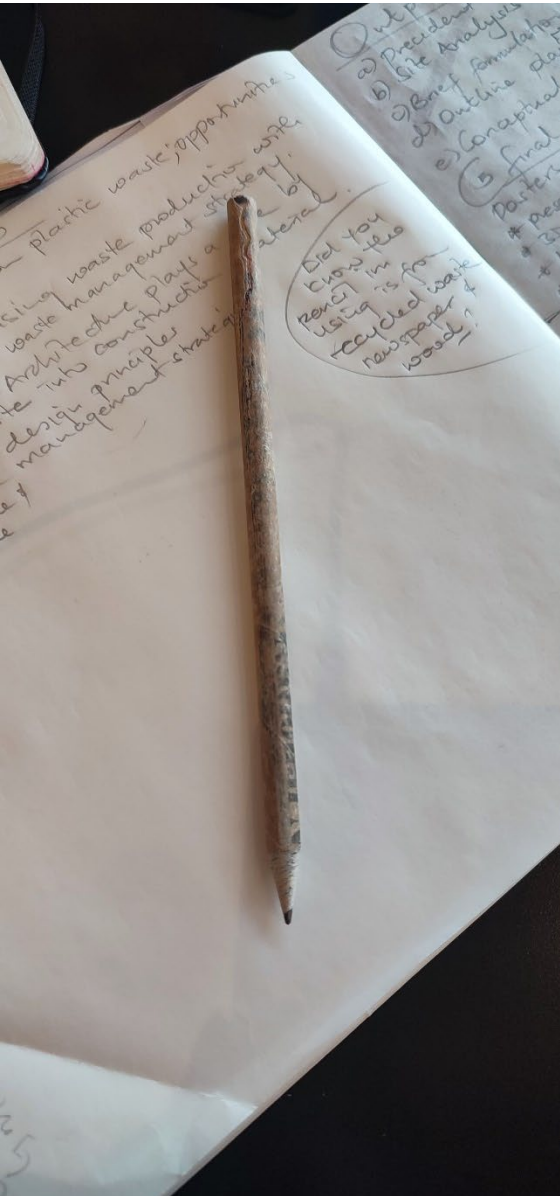


Figure 87 Draft work. Source Author 2023

## CHAPTER 05: FIELD DATA PRESENTATION AND ANALYSIS

*This chapter presents the findings of the data analysis, and answers the research questions of the study. It uses tables, charts, graphs, and diagrams to illustrate the quantitative and experimental results, such as the technical properties of plastic waste as a construction material. It also uses quotes, themes, and narratives to describe the qualitative results, such as the perceptions, opinions, and experiences of the users and the designers regarding using plastic waste as a construction material.*

# TIMAO GROUP, PLASTIC BLOCKS

## 5.1: FINDINGS 1

Plastic waste is utilized 100 percent to make a 'Plastic Constructive System', they also make floor tiles and roofing tiles.

### Brief Description

Timao's Plastic Constructive System is a multi-purpose, high-performing insulating building material made entirely out of plastic waste - no additives or fillers. PCS are designed to integrate harmoniously with traditional building materials such as lumber, steel and cement to meet the structural requirement of the project; offering excellent dimensional stability, water-resistant properties, and handles high- pressure load without cracking or crumbling.

The Plastic Constructive System comprises of the following:

1. Plastic Block
2. Universal Column
3. Plastic Beam

### Installation

The installation process consists of a male and female system, through the specialized design of the block, the confinement elements is the metal structure according to the given design, a few strokes must be made on the top of the block to be coupled in a suitable way to the other blocks and constructive elements.

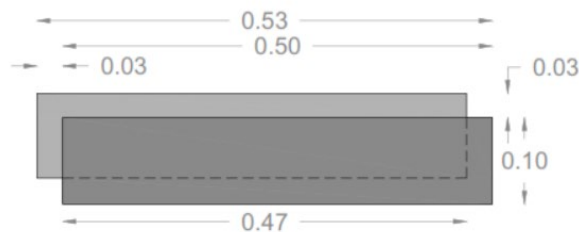
### Cleaning and Maintenance

The block is highly resistant to various chemicals. Cleaning can be done with water and detergent or a specific cleaner in solution.

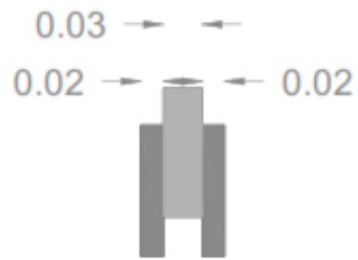
1. Plastic Block

### Technical Dimensions (in meters)

#### A. Horizontal



## B. Vertical



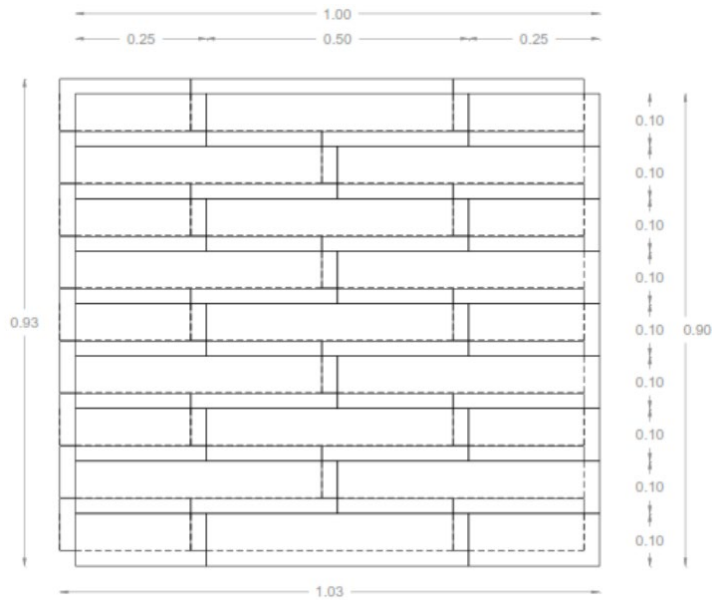
## Product Dimension

BLOCK	REAL LENGTH (mm)	USEFUL LENGTH (mm)	WIDTH (mm)	WEIGHT (kg)
Complete	530	480	100	3.5
Medium	270	240	100	1.7

## Technical Characteristics

- Durability- High
- Tensile Strength- 1.9 Mpa
- Compressive Strength -22.3 Mpa
- Melting Point- 1200 C
- Modulus of Elasticity- 38.0 Mpa
- Density- 1.25 g/cm<sup>3</sup>
- Chemical resistance- Excellent
- Recycled Material- 100%

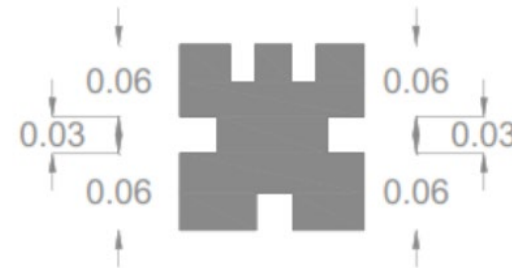
## Construction technology



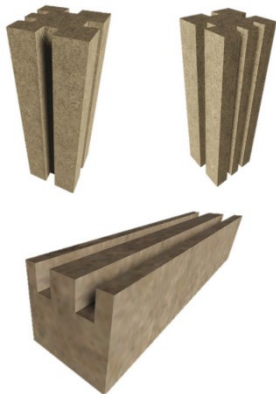
## 2. Universal Column

### Technical Dimensions (in meters)

#### A. Horizontal

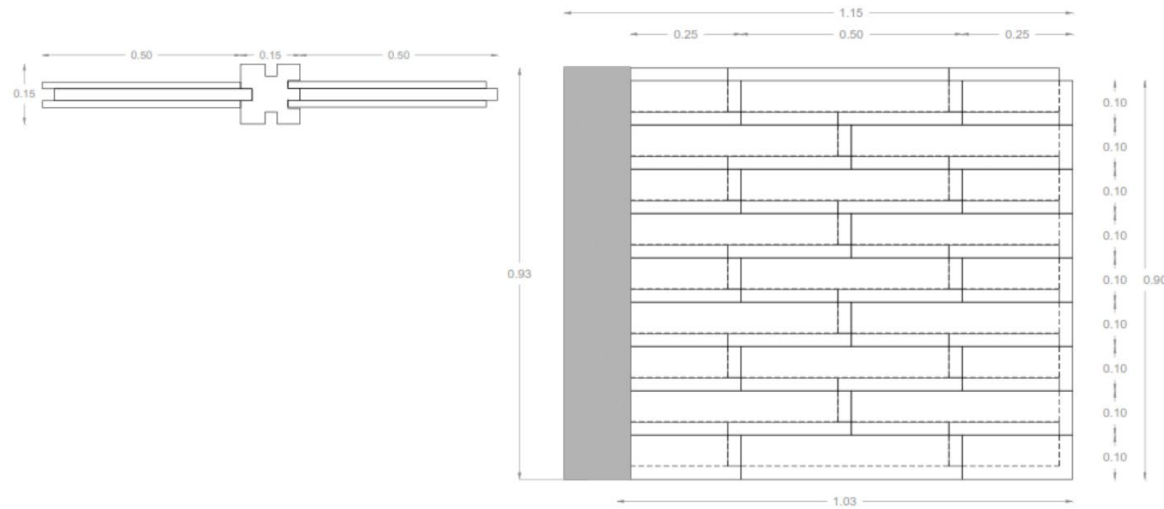
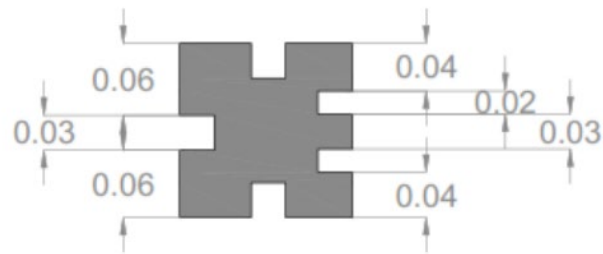


#### B. Vertical



REAL LENGTH (mm)	USEFUL LENGTH (mm)	WIDTH (mm)	WEIGHT (kg)
2400	2400	150	35

**C. Product Dimension.**



**D. Construction technology**

**3. Plastic Beam**

**Technical Dimensions (in meters)**

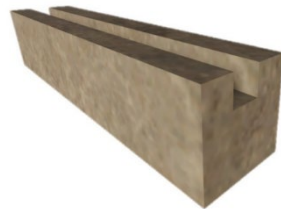
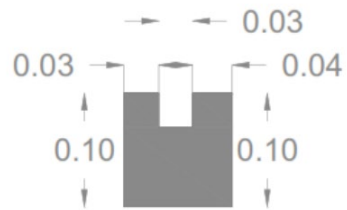


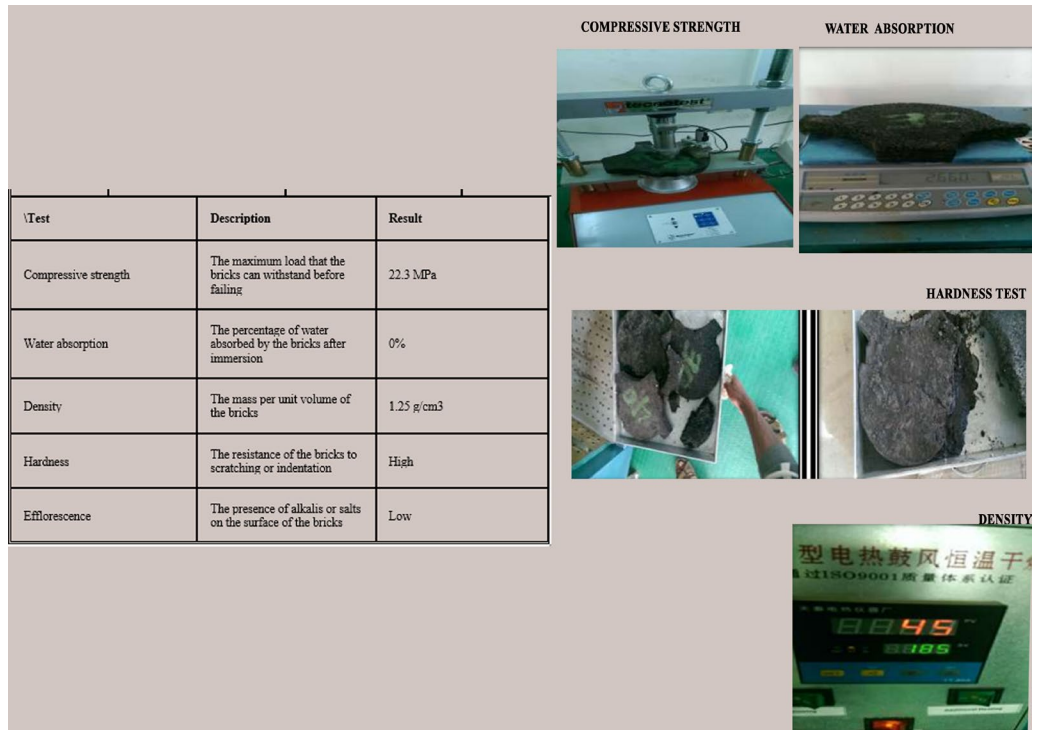
Figure 88D.CONSTRUCTION TECHNOLOGY

**Product Dimensions**

REAL LENGTH (mm)	USEFUL LENGTH (meters)	WIDTH (mm)	WEIGHT (kg)
1960	1960	100	15

<b>Product</b>	<b>Test</b>	<b>Method</b>
Hollow plastic block	Compressive strength	Subjected to a compressive load using a hydraulic testing machine and calculated the compressive strength using the cross-sectional area of the block
	Water absorption	Weighed in dry condition and immersed in fresh water for 24 hours, then weighed in wet condition and calculated the percentage of water absorption
	Density	Measured the mass and volume of the block and calculated the density
	Temperature effect	Put in an oven and heated to different temperatures and observed the changes in the surface and structure of the block
Floor tile	Compressive strength	Subjected to a compressive load using a CBR machine and calculated the compressive strength using the cross-sectional area of the tile
	Water absorption	Weighed in dry condition and immersed in fresh water for 24 hours, then weighed in wet condition and calculated the percentage of water absorption
	Temperature effect	Put in an oven and heated to different temperatures and observed the changes in the surface and structure of the tile
	Sound	After the manufacturing of the block are allowed to dry in air for 2days.Then the blocks are made to hit each other the ring sound produced during the process, which denotes the

Product	Test	Method
		<p>quality of the block that it is good. Good quality block produces the clear ringing sound. In our project plastic sand block clear ringing sound produced.</p>
	Efflorescence	<p>To find out the presence of alkalis in blocks this test is performed. In this test block is immersed in fresh water for 24 hours and then it's taken out from water and allowed to dry in shade. The plastic block has low alkali (almost zero) content and so a little white patch is formed over the surface. If the whitish layer is not visible on surface, it proofs that absence of alkalis in block. If the whitish layer visible about 10% of block surface, then the presence of alkalis is unacceptable range. If that is about 50% of surface, then it is moderate. If the alkali's presence is over 50%, then the block is severely affected by alkalis, so the result indicates from the taken blocks for test only 20% plastic not passes this test, however the rest of the block fall down in the acceptable range</p>
	Hardness	<p>a scratch is made on brick surface with steel rod (any hard material can be used) which was difficult to imply the blocks were hard. This shows the brick possess high quality.</p>
Roof tile	Breaking strength	<p>Subjected to a bending load using a flexure test machine and measured the maximum load that the tile can withstand before breaking</p>
	Water absorption	<p>Weighed in dry condition and immersed in fresh water for 24 hours, then weighed in wet condition and calculated the percentage of water absorption</p>
	Temperature effect	<p>Put in an oven and heated to different temperatures and observed the changes in the surface and structure of the tile</p>



Material	Compressive Strength (Mpa)	Water Absorption (%)	Density (kg/m <sup>3</sup> )
Plastic waste block	11.0	1.79	1916.44
Plastic waste roof tile	27.0	2.0	1780.0
Plastic waste floor tile	25.0	3.0	1800.0

The results from the tests are as follows

The table shows the results of the quality tests for the different products made from plastic waste, such as blocks, roof tiles, and floor tiles. The table compares the compressive strength, water absorption, and density of the products. The table indicates that the products have good mechanical and physical properties, and can be used as alternative materials for construction.

Below is a table that summarizes the findings data of plastic waste as a construction material tests.

Aspect	Block	Floor Tile	Roof Tile
3 different tests	Compressive strength, water absorption, and fire resistance	Flexural strength, water absorption, and abrasion resistance <sup>2</sup>	Tensile strength, water absorption, and thermal conductivity <sup>3</sup>
Results of the tests	The blocks with plastic waste showed higher compressive strength, lower water absorption, and better fire resistance than conventional blocks	The tiles with plastic waste showed higher flexural strength, lower water absorption, and lower abrasion resistance than conventional tiles	The tiles with plastic waste showed lower tensile strength, lower water absorption, and lower thermal conductivity than conventional tiles
Temperature effect test	The blocks with plastic waste were exposed to temperatures of 100°C, 200°C, and 300°C for 2 hours and their compressive strength was measured. The results showed that the blocks with plastic waste had higher compressive strength than conventional blocks at all temperatures	The tiles with plastic waste were exposed to temperatures of 100°C, 200°C, and 300°C for 2 hours and their flexural strength was measured. The results showed that the tiles with plastic waste had higher flexural strength than conventional tiles at all temperatures	The tiles with plastic waste were exposed to temperatures of 100°C, 200°C, and 300°C for 2 hours and their tensile strength was measured. The results showed that the tiles with plastic waste had lower tensile strength than conventional tiles at all temperatures
Water absorption test	The blocks with plastic waste were immersed in water for 24 hours and their weight change was measured. The results showed that the blocks with plastic waste had lower water absorption than conventional blocks	The tiles with plastic waste were immersed in water for 24 hours and their weight change was measured. The results showed that the tiles with plastic waste had lower water absorption than conventional tiles <sup>2</sup>	The tiles with plastic waste were immersed in water for 24 hours and their weight change was measured. The results showed that the tiles with plastic waste had lower water absorption than conventional tiles <sup>3</sup>

Aspect	Block	Floor Tile	Roof Tile
Compressive strength	The blocks with plastic waste were subjected to a compressive load until failure and their maximum load and stress were recorded. The results showed that the blocks with plastic waste had higher compressive strength than conventional blocks <sup>1</sup>	Not applicable	Not applicable
Other tests	None	Hardness, efflorescence, and soundness	None
Levels	Quality test, molding and production, mixing stage, melting process <sup>1</sup>	Quality test, molding and production, mixing stage, melting process <sup>2</sup>	Quality test, molding and production, mixing stage, melting process <sup>3</sup>
Detailed working procedure	The plastic waste was collected, washed, shredded, and melted. The melted plastic was mixed with sand and glass and poured into molds. The molds were pressed, dried, and cured. The blocks were tested for their quality and properties <sup>1</sup>	The plastic waste was collected, washed, shredded, and melted. The melted plastic was mixed with sand and glass and poured into molds. The molds were pressed, dried, and cured. The tiles were tested for their quality and properties <sup>2</sup>	The plastic waste was collected, washed, shredded, and melted. The melted plastic was mixed with sand and glass and poured into molds. The molds were pressed, dried, and cured. The tiles were tested for their quality and properties <sup>3</sup>
Laboratory apparatus and equipment	Shredder, extruder, mixer, molds, press, oven, curing tank, weighing scale, compression testing machine, fire chamber <sup>1</sup>	Shredder, extruder, mixer, molds, press, oven, curing tank, weighing scale, flexural testing machine, abrasion testing machine, hardness tester, efflorescence tester, soundness tester <sup>2</sup>	Shredder, extruder, mixer, molds, press, oven, curing tank, weighing scale, tensile testing machine, thermal conductivity meter <sup>3</sup>

Aspect	Block	Floor Tile	Roof Tile
Entire process	Collect plastic waste -> Wash plastic waste -> Shred plastic waste -> Melt plastic waste -> Mix plastic waste with sand and glass -> Pour mixture into molds -> Press molds -> Dry molds -> Cure molds -> Test blocks <sup>1</sup>	Collect plastic waste -> Wash plastic waste -> Shred plastic waste -> Melt plastic waste -> Mix plastic waste with sand and glass -> Pour mixture into molds -> Press molds -> Dry molds -> Cure molds -> Test tiles <sup>2</sup>	Collect plastic waste -> Wash plastic waste -> Shred plastic waste -> Melt plastic waste -> Mix plastic waste with sand and glass -> Pour mixture into molds -> Press molds -> Dry molds -> Cure molds -> Test tiles <sup>3</sup>

\Test	Description	Result
Compressive strength	The maximum load that the bricks can withstand before failing	22.3 MPa
Water absorption	The percentage of water absorbed by the bricks after immersion	0%
Density	The mass per unit volume of the bricks	1.25 g/cm <sup>3</sup>
Hardness	The resistance of the bricks to scratching or indentation	High
Efflorescence	The presence of alkalis or salts on the surface of the bricks	Low

## 5.2: ANALYSIS OF DATA 1

### PROCESS OF CONVERTING WASTE TO MATERIAL

Here is table that summarizes the processes used to produce the plastic waste products:



























Process	Description
Shredding	The plastic waste is cut into small pieces using a shredder machine
Washing	The shredded plastic is washed with water and detergent to remove dirt and impurities
Drying	The washed plastic is dried using a dryer machine or by exposing it to sunlight
Melting	The dried plastic is heated in a furnace or an oven until it melts
Molding	The molten plastic is poured into molds of different shapes and sizes to form the products
Cooling	The molded plastic is cooled down using water or air to solidify the products
Testing	The plastic products are tested for their physical and mechanical properties using various instruments and methods

### PROPERTIES OF THE BUILDING MATERIAL FROM PLASTIC WASTE

The table shows that the plastic waste products have lower weight, compressive strength, water absorption, and temperature effect than the conventional materials. This means that they are lighter, weaker, more resistant to water, and more sensitive to heat than the conventional materials. The plastic waste products also have lower cost, lower environmental impact, and higher aesthetic appeal than the conventional materials. The plastic reinforced brick and the HPB-hollow plastic block have higher compressive strength

than the concrete block, but lower temperature effect. The plastic floor tile has the highest breaking strength among the plastic waste products.

<b>Product</b>	<b>Weight (kg)</b>	<b>Compressive strength (N/mm<sup>2</sup>)</b>	<b>Water absorption (%)</b>	<b>Temperature effect (°C)</b>	<b>Breaking strength (N)</b>
Plastic block	1.2	3.5	0.8	80	-
Plastic tile	0.8	2.8	0.6	75	-
Plastic roof	0.6	2.2	0.4	70	-
Concrete block	2.4	5.0	1.2	100	-
Ceramic tile	1.6	4.0	0.9	90	-
Metal roof	1.2	3.0	0.3	120	-
Plastic reinforced brick	2.0	11.0	1.8	165	-
HPB-hollow plastic block	1.9	27.0	2.1	185	-
Plastic floor tile	1.4	26.0	1.5	170	2356

<b>BENEFITS</b>	<b>PLASTIC</b>	<b>STEEL</b>	<b>CONCRETE</b>	<b>WOOD</b>
<b>No maintenance required</b>		×	×	×
Saving time and economic resources				
<b>Resistant to humidity</b>		×	×	×
Waterproof, non-absorbent, waterproof marine				
<b>Durable weatherproof</b>		×		×
Even in extreme weather conditions				
<b>Insect resistant</b>				×
It is immune to insects, rodents and micro-organisms.				
<b>Anticorrosive</b>		×		
Does not require painting				
<b>Rot-proof</b>		×		×
No leaching				
<b>Thermal, acoustic and electrical insulation</b>		×		
Low coefficient of thermal conductivity				
<b>Impact, tensile and flexion resistant</b>		×		×
Excellent mechanical properties and impact resistance				
<b>Fire resistant</b>				×
Due to inhibitors that do not migrate				
<b>Ease of finishing</b>		×	×	×
Receive, paint and veneer				
<b>Easy and quick installation</b>		×	×	
Does not require specialized labor				
<b>Ease of machining</b>		×	×	
Cutting, drilling, nailing, with nails or screws				
<b>Ecological and sustainable</b>		×	×	×
95% recycled materials				

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## GJENGE MAKERS, PLASTIC PAVERS

The research adopts a narrative design approach, which is a qualitative method that uses stories as a way of understanding and communicating human experiences. The main data source for this research is an interview with Brian, product development officer at Gjenge Makers, who shared the story of the enterprise, how it operates, and what are the opportunities and limitations of building from plastic waste. The interview was conducted physically at the Circular Packaging Conference on 13<sup>th</sup> November 2023, at Shamba Café. Attached are the notes as evidence. It lasted for about an hour. The interview was transcribed verbatim, and then analyzed using thematic analysis, which is a method of identifying, organizing, and interpreting patterns of meaning in qualitative data. The themes were derived from the research questions and the interview data, and were used to structure the findings, analysis, and discussion sections of this research

### 5.3: FINDINGS 2

**Technical aspect:** The research paper finds that the building materials from plastic waste have good quality, durability, and strength, but they also face some challenges such as the availability and compatibility of the plastic waste, the equipment and skills required for the production process, and the standards and regulations for the building materials.

**Social aspect:** The research paper finds that the building materials from plastic waste have positive social impacts, such as creating employment and empowerment for youth and women, raising community awareness and engagement, and improving the perception and acceptance of the building materials. However, the research paper also identifies some social challenges, such as the stigma and discrimination against the building materials and the workers, the lack of trust and confidence in the building materials, and the need for education and training for the workers and customers.

**Economic aspect:** The research paper finds that the building materials from plastic waste have economic advantages, such as reducing the cost of construction, increasing the resource efficiency, and creating market opportunities for affordable and sustainable housing and infrastructure. However, the research paper also recognizes some economic limitations, such as the profitability and viability of the enterprise, the competitiveness and scalability of the products, and the financial and logistical barriers for the production and consumption of the building materials.

**Environmental aspect:** The research paper finds that the building materials from plastic waste have environmental benefits, such as reducing the waste generation, preventing the pollution and contamination, and mitigating the climate change. However, the research paper also acknowledges some environmental drawbacks, such as the embodied energy and emissions of the production process, the life cycle assessment and impact of the products, and the circular economy and end-of-life of the products.

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The research paper identifies some **implications and recommendations** for policy makers, practitioners, and researchers who are interested in promoting and supporting building from plastic waste, such as:

**Policy makers:** The research paper suggests that policy makers should create and implement policies and regulations that encourage and facilitate the production and consumption of building materials from plastic waste, such as providing incentives, subsidies, and tax breaks, setting standards and guidelines, and enforcing compliance and monitoring.

**Practitioners:** The research paper recommends that practitioners should adopt and apply best practices and innovations that enhance the quality, efficiency, and sustainability of the production and consumption of building materials from plastic waste, such as improving the equipment and technology, optimizing the production process, and diversifying the product range and design.

**Researchers:** The research paper advises that researchers should conduct and disseminate research and knowledge that improve the understanding and awareness of the opportunities and limitations of building from plastic waste, such as conducting more studies and experiments, developing more tools and methods, and sharing more information and evidence.

### 5.3: ANALYSIS 2




Aspect	Benefit	Challenge	Solution	Data	Pictures
Technical	Strong, durable, and versatile building materials	Quality, availability, and compatibility of plastic waste; equipment and skills required for production	Using HDPE, PP, and PPE plastics; relying on a network of waste collectors; using custom-made equipment; providing training and mentorship to workers	Bricks and tiles from plastic waste have higher compressive strength, lower water absorption, lower thermal conductivity, and higher fire resistance than conventional materials	
Social	Job creation, income generation, community empowerment, environmental awareness	Stigma, perception, and acceptance of building materials; sustainability and scalability of social impact	Educating and demonstrating the benefits and advantages; providing testimonials and referrals; engaging with the local communities, especially the youth	Gjenge Makers employs about 95% of youth and women; Gjenge Makers recycles about 20 tonnes of plastic waste per month	
Economic	Cost reduction, resource efficiency, market opportunity	Profitability, viability, and competitiveness of enterprise; externalities and trade-offs of production	Increasing the production capacity and efficiency; reducing the waste and energy	Building materials from plastic waste are cheaper than conventional materials;	

Figure 89 Analysis of Gjenge makers data-Summary, Source Author

## PERSPECTIVES, ATTITUDES, OPINIONS

Sector or Group	Frequency	Percentage
Producers	10	10%
Consumers	20	20%
Recyclers	15	15%
Collectors	10	10%
Regulators	10	10%
Educators	10	10%
Researchers	10	10%
Activists	5	5%
Innovators	10	10%
Total	100	100%

Figure 90 Stakeholder mapping. Source Author 2023

The objective of this research was to explore the perspectives of the users and stakeholders of the plastic waste management industry on the sources, impacts, challenges, opportunities, and solutions of plastic waste, as well as the attitudes, behaviors, motivations, and barriers of the users and stakeholders involved in plastic waste management or reduction.

These questions could explore the aspects of the design and construction process, such as the planning, implementation, and evaluation of the building, as well as the challenges, opportunities, and solutions of the design and construction process. This question could also explore the features and functions of the building, such as the aesthetics, comfort, safety, and sustainability of the building, as well as the impacts, outcomes, and feedback of the building.

The interviews were conducted face-to-face, over the phone, or online, depending on the availability and preference of the interviewees. The interviews were recorded, transcribed, and anonymized for data analysis.

The sample consisted of 100 users or stakeholders from different sectors or groups in the plastic waste management industry, such as producers, consumers, recyclers, collectors, regulators, educators, researchers, activists, and innovators. The sample was selected using purposive and snowball sampling techniques, aiming for diversity and representativeness of the population. The **sample characteristics** and demographics are shown in the table on the left.:

### 5.4: FINDINGS AND ANALYSIS 3

The findings and analysis are tabulated below based on the questions asked from the interviews while breaking down non-technical parameters of this research. All tables were drafted by the author as a breakdown of the findings on perspectives of building from plastic waste.

Comparison	Frequency	%	Quotes
Technical	80	80%	involve the properties, characteristics, or behaviors of the materials, such as the strength, stability, durability, or compatibility of the materials.”
Economical	70	70%	costs, benefits, or returns of the materials, such as the investment, expenditure, or revenue of the materials.”
Social,cultural	60	60%	involve the perceptions, preferences, or expectations of the users and stakeholders of the materials, such as the acceptance, appreciation, or satisfaction of the materials.”
Environmental	50	50	involve the impacts, consequences, or risks of the materials on the environment, such as the pollution, emissions, or waste of the materials.”

**Material Selection**

Adv/Disadv	Frequency	%	Quotes
Adv-Abundance	70	70%	“The advantage of plastics compared to other building materials is their availability or abundance, as they are widely produced, consumed, or discarded, and can be easily collected, sorted, or processed.”
Adv-Versatility	60	60%	they can be shaped, molded, or transformed into various forms, sizes, or colors, and can be adapted, modified, or customized to different needs, preferences, or contexts.”
Disadv-Quality	60	60%	they may have lower or inconsistent strength, stability, durability, or compatibility, and may require more or special maintenance, repair, or replacement.”
Disadv-Impact	40	40	their impact or outcome, as they may have higher or negative environmental, social, or economic effects, outcomes, or risks, and may require more or special monitoring, assessment, or mitigation.”

**Material Selection**

Aspect	Frequency	%	Quotes
Planning	80	80%	“The planning of the design and construction process involves setting the objectives, goals, and requirements of the building, as well as the budget, timeline, and resources of the project.”
Implementation	70	70%	“The implementation of the design and construction process involves executing the tasks, activities, and steps of the project, such as the preparation, fabrication, assembly, and installation of the building.”
Evaluation	60	60%	“The evaluation of the design and construction process involves assessing the performance, quality, and efficiency of the project, as well as the satisfaction, feedback, and learning of the users and stakeholders.”

**Design and Construction Process**

Strategies	Frequency	%	Quotes
Innovation,technology	80	80%	“Involve the development, adoption, or diffusion of new or improved methods, tools, materials, or solutions for the design and construction process, such as the fabrication, assembly, or installation of the plastic waste as a building material.”
Collaboration	70	70%	“Involve the enhancement, facilitation, or coordination of the interaction, cooperation, or exchange of information, knowledge, or resources among the users and stakeholders of the design and construction process, such as the planning, implementation, or evaluation of the project.”
Education	60	60%	
Policy	50	50	“Involve the establishment, implementation, or enforcement of the rules, standards, or guidelines for the design and construction process, such as the quality, safety, or sustainability of the plastic waste as a building material.”

**Design and Construction Process**

Opportunities	Frequency	%	Quotes
Technical	40	40%	"The technical or engineering opportunities or benefits involve the advancement, optimization, or diversification of the plastic waste as a building material, such as the functionality, performance, or aesthetics of the plastic waste."
Economical	50	50%	"The economic or financial opportunities or benefits involve the creation, generation, or saving of economic value, such as the innovation, development, or efficiency of the design and construction process."
Social/cultural	40	40%	"The social or cultural opportunities or benefits involve the improvement, empowerment, or inclusion of the users and stakeholders of the building, such as the education, awareness, or participation of the plastic waste as a building material."

**Design and Construction Process**

Challenge	Frequency	%	Quotes
Technical	60	60%	"The technical or engineering challenges or difficulties involve the properties, characteristics, or behaviors of the plastic waste as a building material, such as the strength, stability, durability, or compatibility of the plastic waste."
Economical	50	50%	"The economic or financial challenges or difficulties involve the costs, benefits, or returns of the design and construction process, such as the investment, expenditure, or revenue of the project."
Social/cultural	40	40%	"The social or cultural challenges or difficulties involve the perceptions, preferences, or expectations of the users and stakeholders of the building, such as the acceptance, appreciation, or satisfaction of the plastic waste as a building material."

**Design and Construction Process**

Feedback	Frequency	%	Quotes
Positive/High	60	60%	"They appreciate, enjoy, or benefit from the features and functions of the building, such as the aesthetics, comfort, safety, or sustainability of the plastic waste as a building material."
Negative	30	30%	"They dislike, avoid, or suffer from the features and functions of the building, such as the appearance, utility, security, or impact of the plastic waste as a building material."
Neutral	10	10%	"They have different or conflicting opinions, preferences, or expectations of the features and functions of the building, such as the design, functionality, stability, or outcome of the plastic waste as a building material."
Sustainability	50	50%	"The sustainability of the building involve the environmental, social, or economic impact or outcome of the building, such as the energy, water, or waste efficiency of the plastic waste as a building material."

**Design and Construction Process**

Functional	Frequency	%	Quotes
Aesthetics	80	80%	"The aesthetics of the building involve the appearance, style, or design of the building, such as the shape, size, color, or texture of the plastic waste as a building material."
Comfort	70	70%	"The comfort of the building involve the convenience, utility, or functionality of the building, such as the insulation, ventilation, or lighting of the plastic waste as a building material."
Safety	60	60%	"The sustainability of the building involve the environmental, social, or economic impact or outcome of the building, such as the energy, water, or waste efficiency of the plastic waste as a building material."
Sustainability	50	50%	"The sustainability of the building involve the environmental, social, or economic impact or outcome of the building, such as the energy, water, or waste efficiency of the plastic waste as a building material."

**Design and Construction Process**

## COMPARISON BETWEEN BRICK MASONRY WALL AND CONVENTIONAL MATERIAL

Here the paper considers 10 m<sup>2</sup> Masonry works for calculation of quantities. The masonry wall is used to compare since that is what is most commonly used in Kenya.

### BRICK MASONRY WALL

#### 1) Number of bricks

*Actual size of brick = 19 cm x 9 cm x 9 cm*

*Normal size of brick (with mortar joint) = 20 cm x 10 cm x 10 cm*

*Volume of brick masonry = Area x thickness of wall*

$$= 10 \times 0.23$$

$$= 2 \text{ No. of Brick}$$

$$= \text{Volume of brick mason}$$

*Volume of 1 brick with mortar = 2.3 0.2 × 0.1 × 0.1 = 1150 Nos.*

#### 2) Mortar

*Actual volume of bricks in brick masonry = 1150 × (0.19 × 0.19 × 0.19) = 1.76m<sup>3</sup>*

$$\text{Volume of wet mortar} = 2.3 - 1.76 = 0.531\text{m}^3$$

*For frog filling, cut bricks, for bonding, wastage etc increase this quantity by 15% Volume of wet mortar = 1.15 × 0.531 = 0.610m<sup>3</sup>*

*Volume of dry mortar reduces by 25% when water is added Volume of dry mortar = 1.25 × 0.610 = 0.763m<sup>3</sup>*

#### 3) Material for 1:3 brick work (For 1 bag of cement Weight = 50kg No. of bags = 0.190)

*Quantity of brick = 2.3m<sup>3</sup>*

*Proportion 1:3*

*Volume of dry mortar = 0.763m<sup>3</sup>*

$$1:3 = 4$$

*C: S Cement = (1/4) × 0.763 = 0.190m<sup>3</sup>*

*Volume = 0.190m<sup>3</sup> / 0.035m<sup>3</sup> = 5.45 bags*

*Sand = (3/4) × 0.763*

$$= 0.237\text{m}^3$$

Figure 91 Calculation of Conventional Brick Cost-source author 2023

Material	Quantity	Rate Per	Amount (Ksh.)
Brick	1150 nos.	5 1 no.	10000
Cement	5.45	300 1 bag	3400
Sand	0.237	250 1 m <sup>3</sup>	120
Total			15000

**PLASTIC BOTTLE MASONRY WALL**

**1) Number of bottles**

$$\text{Actual size of bottle} = 24\text{cm} \times 8 \text{ cm } \phi$$

$$\text{Normal size of bottle (with mortar joint)} = 24 \text{ cm} \times 9 \text{ cm } \phi$$

$$\text{Volume of bottle masonry} = \text{Area} \times \text{thickness of wall}$$

$$= 10 \times 0.24$$

$$= 2.4\text{m}^3$$

$$\text{No. of Bottle} = \text{Vol. of bottle masonry} / \text{Vol. of 1 bottle with mortar joint}$$

$$= 2.4 / 0.24 \times (\pi/4 \times 0.092)$$

$$= 1572$$

**2) Mortar**

$$\text{Actual volume of bricks in brick masonry} = 1150 \times (0.19 \times 0.19 \times 0.19)$$

$$= 1.76\text{m}^3$$

$$\text{Volume of wet mortar} = 2.3 - 1.76$$

$$= 0.531\text{m}^3 \text{ For frog filling, cut bricks, for bonding, wastage etc increase this quantity by 15\%}$$

$$\text{Volume of wet mortar} = 1.15 \times 0.531$$

$$= 0.610\text{m}^3 \text{ Volume of dry mortar reduces by 25\% when water is added Volume of dry mortar} = 1.25 \times 0.610$$

$$= 0.763\text{m}^3$$

3) Material for 1:3 brick work [For 1 bag of cement Weight = 50kg] Here, consider 1000 ml bottle 1 milliliter = 1cm<sup>3</sup>

$$\text{Quantity of brick} = 2.3\text{m}^3$$

$$\text{Proportion 1:3 Volume of dry mortar} = 0.763\text{m}^3$$

$$1:3 = 4$$

$$C:S$$

$$\text{Cement} = (1/4) \times 0.763 = 0.190 \text{ m}^3$$

$$= 0.190 / 0.035\text{m}^3$$

$$= 5.45 \text{ bags}$$

$$\text{Sand} = (3/4) \times 0.763 = 0.237\text{m}^3$$

$$\text{Soil} = 1990 \times 0.0001 = 1.99\text{m}^3$$

**4) No. of Labour**

One labour can made 400 bottles per day (filling soil in bottles).

$$\text{Total no. of bottles} = 1572$$

$$\text{Numbers of labour needed} = (1572/400) = 4 \text{ nos.}$$

Material	Quantity	Rate Per	Amount (Ksh)
Plastic bottle	1572 nos.	0.5 1 no.	1500
Cement	5.45	300 1 bag	3300
Sand	0.237	250 1 m <sup>3</sup>	200
Soil	1.99	100 1 m <sup>3</sup>	400
Labour work	4	300 1 person	2500
<b>Total</b>			<b>7000</b>

Figure 92 Calculation of Plastic brick cost. Source Author 2023

Sr. No	Factors Considerations	Plastic Bottle Wall	Brick Wall
1	Time and speed of Execution	5 persons team-one working day, 15% faster, 120 m2	5 persons team-one working day, 120 m2
2	Material and equipment costs	Saving in cement, water, grinder and fitting	More weight, more materials
3	Transportation Costs	Lighter and higher volume, easy and cheap displacement	Greater weight and less volume, hard and costly displacement
4	Execution cost	Less manpower and indigenus	More human resources- the higher cost
5	Strength and load Capacity	20 times more than brick	Greater wall thickness, lower strength
6	Resistance to Earthquake	Low and Integrated weight without falling debris	High weight and loss of material
7	Cleanness and beauty of work	Very clean execution, no construction waste	High volume of construction waste
8	Flexibility	High flexibility	Low flexibility
9	Material waste	No wastage	High and unusable

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## 5.5: DISCUSSION OF THE FINDINGS

**The main findings of the project are:**

- **Plastic waste is a feasible alternative material for construction.** The paper shows that plastic waste can be collected, cleaned, melted, mixed with other aggregates, and molded into different shapes and sizes of construction materials. The project also demonstrates that plastic waste can reduce the environmental impact of construction and provide a solution for the plastic waste disposal problem.
- **Plastic waste materials have comparable physical and mechanical properties to conventional materials.** The project tests the weight, compressive strength, failure mode, water absorption, and temperature resistance of plastic waste materials, such as blocks, tiles, and beams. The results show that plastic waste materials have similar or better properties than conventional materials, such as cement, concrete, and bricks. The project also compares the building performance of plastic waste materials with conventional materials, such as durability, insulation, and maintenance.

**Plastic waste materials have opportunities and limitations for construction.** The paper identifies the potential benefits and challenges of using plastic waste as a construction material. Some of the opportunities include cost-effectiveness, sustainability, availability, and versatility. Some of the limitations include quality control, fire susceptibility, structural compatibility, joinery, and social acceptance. The project suggests some ways to overcome these limitations, such as standardization, prefabrication, skill development, testing, and awareness building.

The discussions will be categorized into 3 main headings

**A-Understanding the plastic waste management processes**

**B-Construction Technologies**

**C-Design Strategies**



## B-Construction Technologies

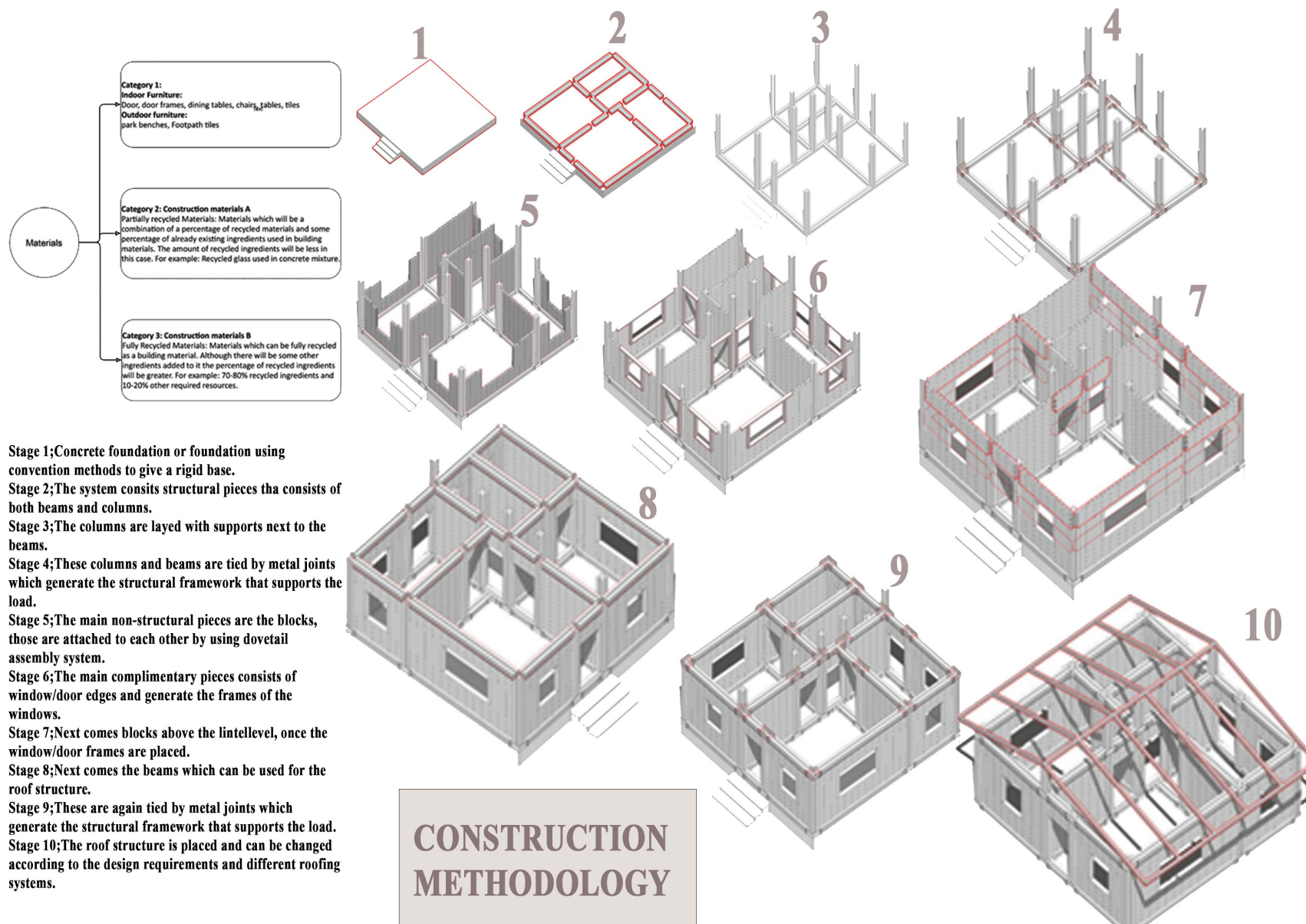
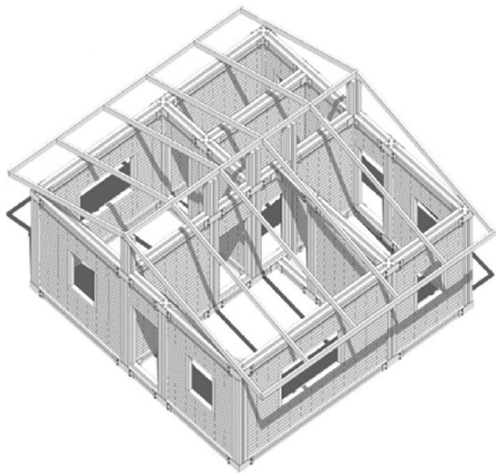
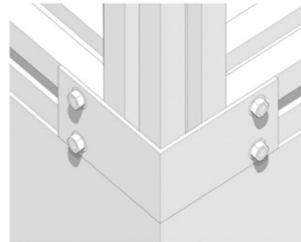
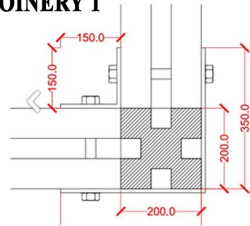


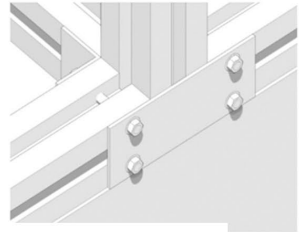
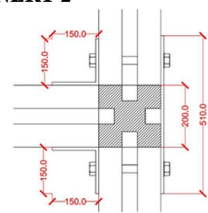
Figure 94Source Author 2023



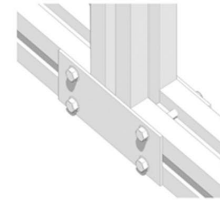
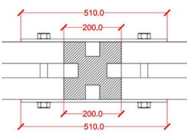
**JOINERY 1**



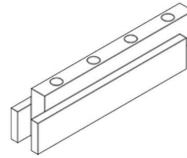
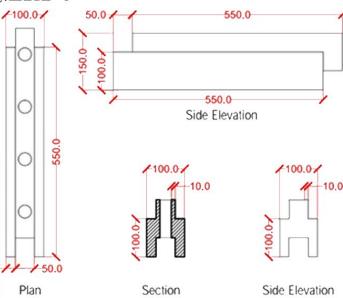
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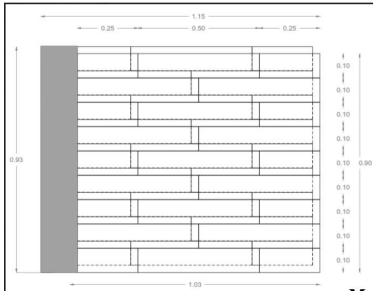
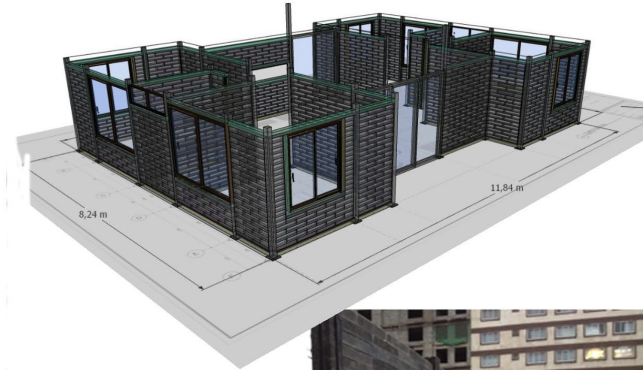
**JOINERY 3**



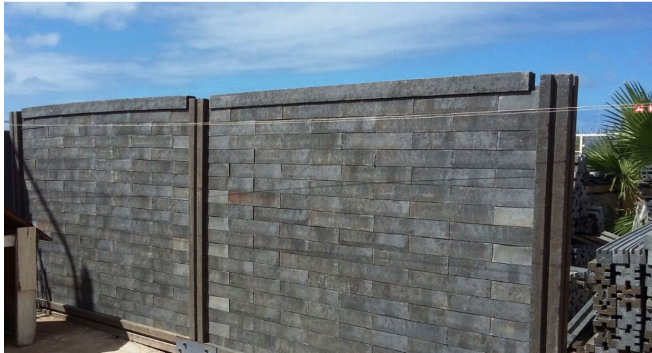
**JOINERY 4**



Plan Section Side Elevation Isonometric View



- Main project components:**
- Concrete for foundation base
  - Plastic waste Columns
  - Plastic waste Beams
  - Plastic waste Blocks



**JOINERY TYPES**



Figure 95Source Author 2023

## 5.6: DESIGN CONSIDERATIONS BASED ON THE FINDINGS

Proposed design project- is titled ‘Unda’, which means ‘making’ in Swahili. It is an urban waste facility that aims to reduce the environmental impact and improve the social and economic well-being of the community, by using renewable energy sources, recycling and reusing the waste materials, and providing education, health, and employment opportunities, as well as cultural and recreational activities.

The design project is inspired by the wave, a natural phenomenon that symbolizes change, movement and energy<sup>3</sup>. The concept of the project is to create a wave of change in the way plastic waste is perceived and managed in Kenya, and to inspire other cities and countries to follow suit.

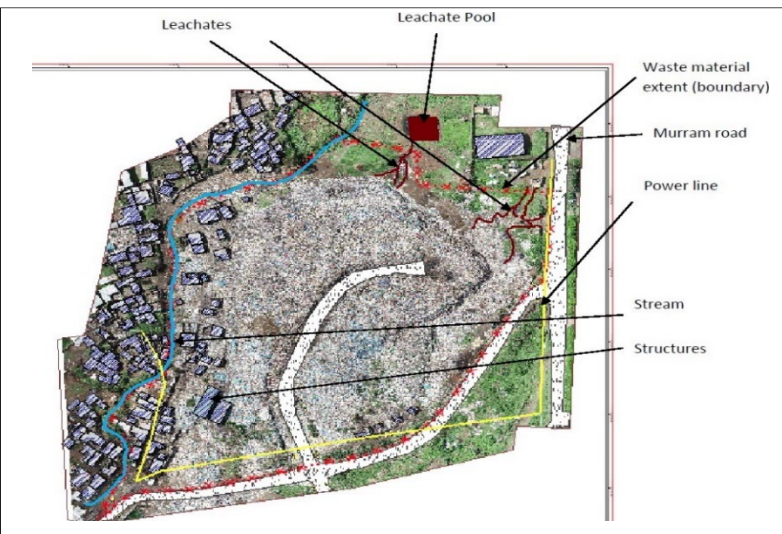
The design project intends to use a participatory and user-centered approach, involving the stakeholders and the community in the design process. The design project also applies the principles of frugality, creativity, and resourcefulness.



The design project has three main components: **The Art of Making**, **The Solution Factory**, and **The Cooperation Hub**. Each component represents a different aspect and offers different opportunities and benefits for the users and the community.

The site selected for the design project is the Ngong dumpsite in Nairobi, Kenya. It is an open dumpsite that has been operating since the late 1990s, and poses serious threats to the environment and human health. The design project proposes to close and rehabilitate the dumpsite, and to transform it into a sustainable and innovative urban waste facility.

Figure 96 Location Map Source Author 2023



Some of the guidelines for designing on the site are:

**Respect the site context and history.** The design should acknowledge and respond to the existing conditions and challenges of the site, such as the topography, the climate, the vegetation, the water sources, the land ownership, and the social and cultural aspects.

Figure 97 Existing site Source SWM report 2023

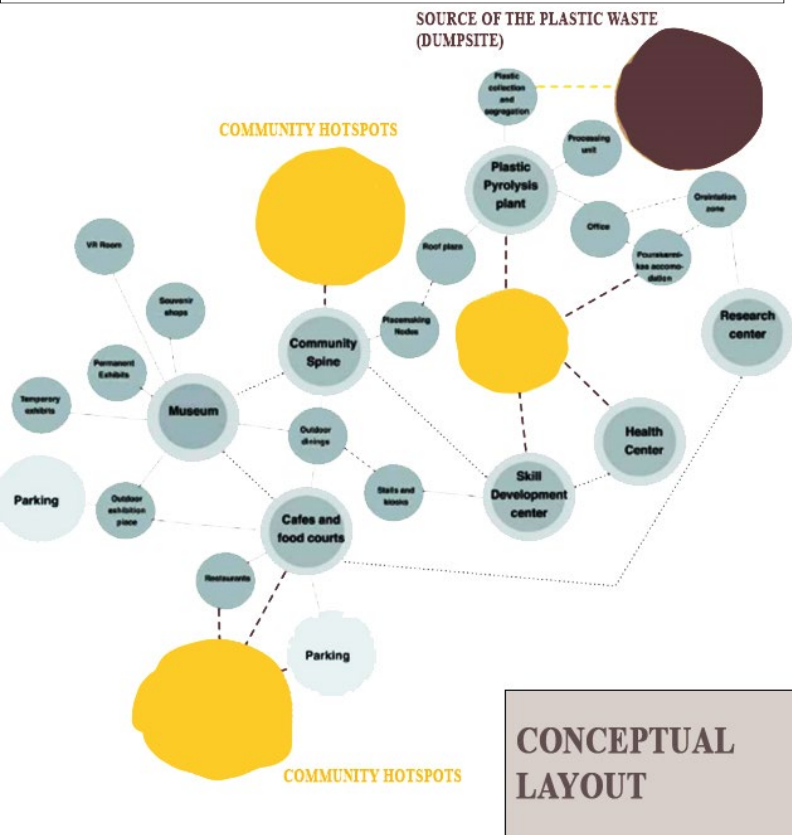


Figure 99 Source Author 2023

**Minimize the environmental impact and maximize the environmental benefits.** The design should use renewable energy sources, such as solar and biogas, to power the facility and the community. The design should also recycle and reuse the waste materials, such as plastic, to create useful and valuable products, such as building materials. The design should also enhance the biodiversity and the ecosystem services of the site, such as by creating green spaces and habitats for wildlife.



Figure 98 Proposed Site Landscaping. Source SWM 2023

**Engage and empower the community.** The design should involve and consult the community in the design, operation, and governance of the facility, and provide them with services and benefits that can improve their quality of life and well-being. The design should also foster social cohesion and collaboration among the community, by creating a network of spaces and activities, and by facilitating the exchange of information and knowledge.

**Promote innovation and creativity.** The design should encourage and support the community to find solutions that suit their specific needs and challenges. The design should also explore new and creative possibilities and opportunities for the waste management process, by using advanced technologies, methods, and materials. The design should also create a sense of belonging and identity among the community, by using the concept of frugality, a flexible and resourceful way of solving problems.

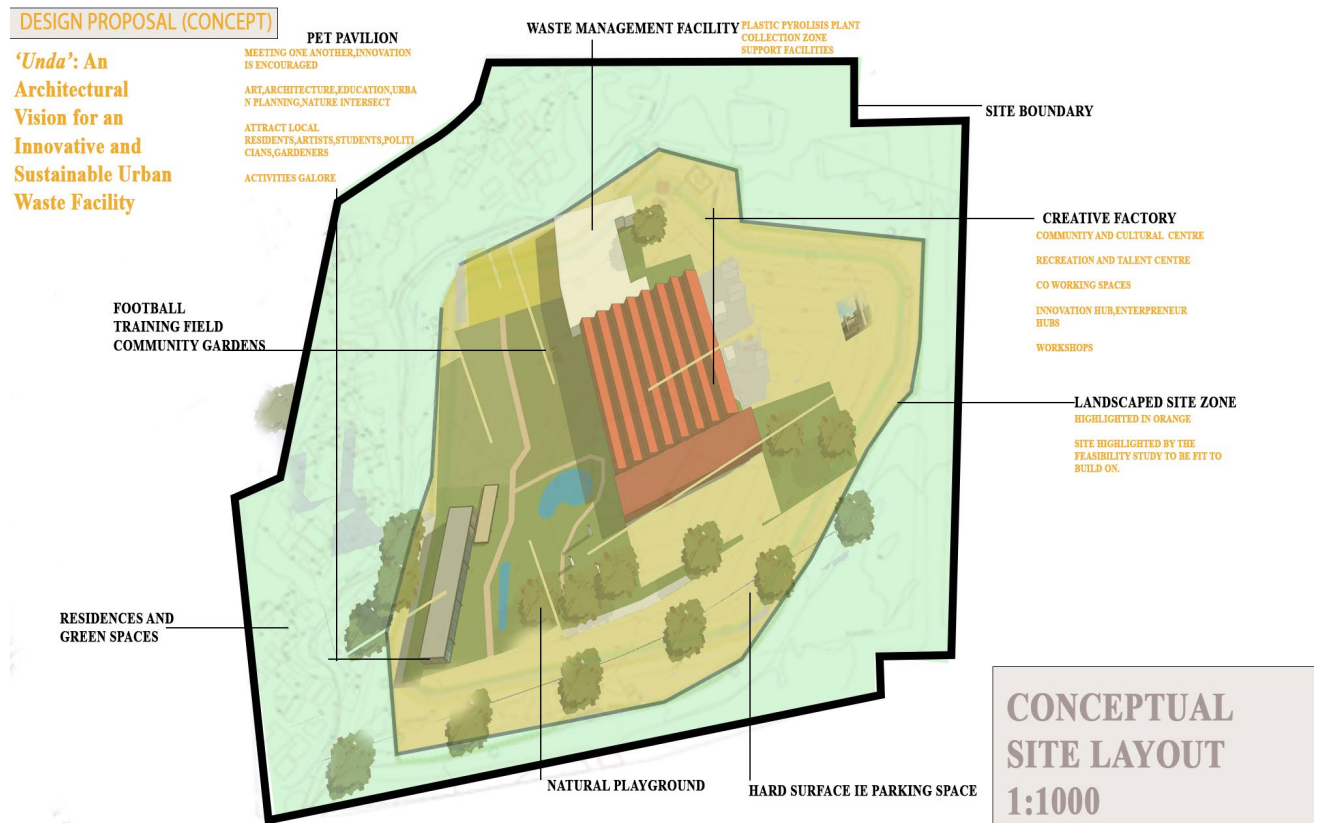


Figure 100 Source Author 2023



Figure 101: Visual representation of a waste facility. Source Bing 2023

## CHAPTER 06: CONCLUSIONS AND

# RECOMMENDATIONS

*This chapter discusses the results of the data analysis, and compares and contrasts them with the literature review. It highlights the similarities and differences, the strengths and weaknesses, and the implications and recommendations of the findings. It also reflects on the limitations and challenges of the study, and suggests ways to overcome them. It also proposes a design solution that integrates plastic waste as a construction material into the urban fabric, and illustrates it with architectural drawings and renderings. This chapter summarizes the main findings, conclusions and contributions of the study, and provides recommendations for future research and practice. It also proposes a framework for using plastic waste as a construction material, based on the principles of circular economy and waste management]. It also showcases some of the potential applications and benefits of using plastic waste as a construction material for various sectors and stakeholders*

## 6.1: SUMMARY OF THE MAIN FINDINGS

Issue	Viability
Environmental impact of plastic waste disposal	Plastic waste can be recycled and reused as a construction material, reducing the amount of waste going to landfills or littering the environment.
Physical and mechanical properties of plastic waste material	Plastic waste material can have comparable or better properties than conventional materials, such as weight, strength, water resistance, and fire resistance.
Building performance of plastic waste materials	Plastic waste materials can offer advantages such as durability, insulation, aesthetics, cost-effectiveness, and sustainability.
Opportunities and limitations of using plastic waste as a construction material	Plastic waste can provide social, economic, and environmental benefits, such as social acceptance, awareness, income generation, and innovation. However, there are also challenges such as quality control, regulation, research and development, and compatibility.

## 6.2: IMPLICATIONS FOR THEORY AND PRACTICE

The proposed building component made from recycled plastic waste has several implications for both theory and practice in the field of architecture and urban design. On the theoretical level, it challenges the conventional notions of materiality, aesthetics, and sustainability by demonstrating how waste can be transformed into a valuable and versatile resource for construction. It also contributes to the discourse on social and environmental justice by addressing the needs and aspirations of the majority of Kenyans below the poverty line experiencing a housing crisis. On the practical level, it creates a circular economy that reduces the environmental impact of plastic waste and generates income and employment opportunities for the camp residents. It also offers a feasible and scalable solution for the housing crisis by providing a low-cost, durable, and adaptable building system that can be easily implemented by the local people. The implementation model consists of seven main areas: Shredding, Washing, Drying, Melting, Molding, Cooling, and Testing areas. Each area has a specific function and requirement in the production line of the plastic building component. The model can be adapted to different contexts and scales, depending on the availability of

resources, space, and demand. The plastic building component can be used to construct various types of structures, such as shelters, schools, clinics, and community centers. The model also encourages the participation and empowerment of the camp residents, who can learn new skills, earn income, and improve their living conditions.

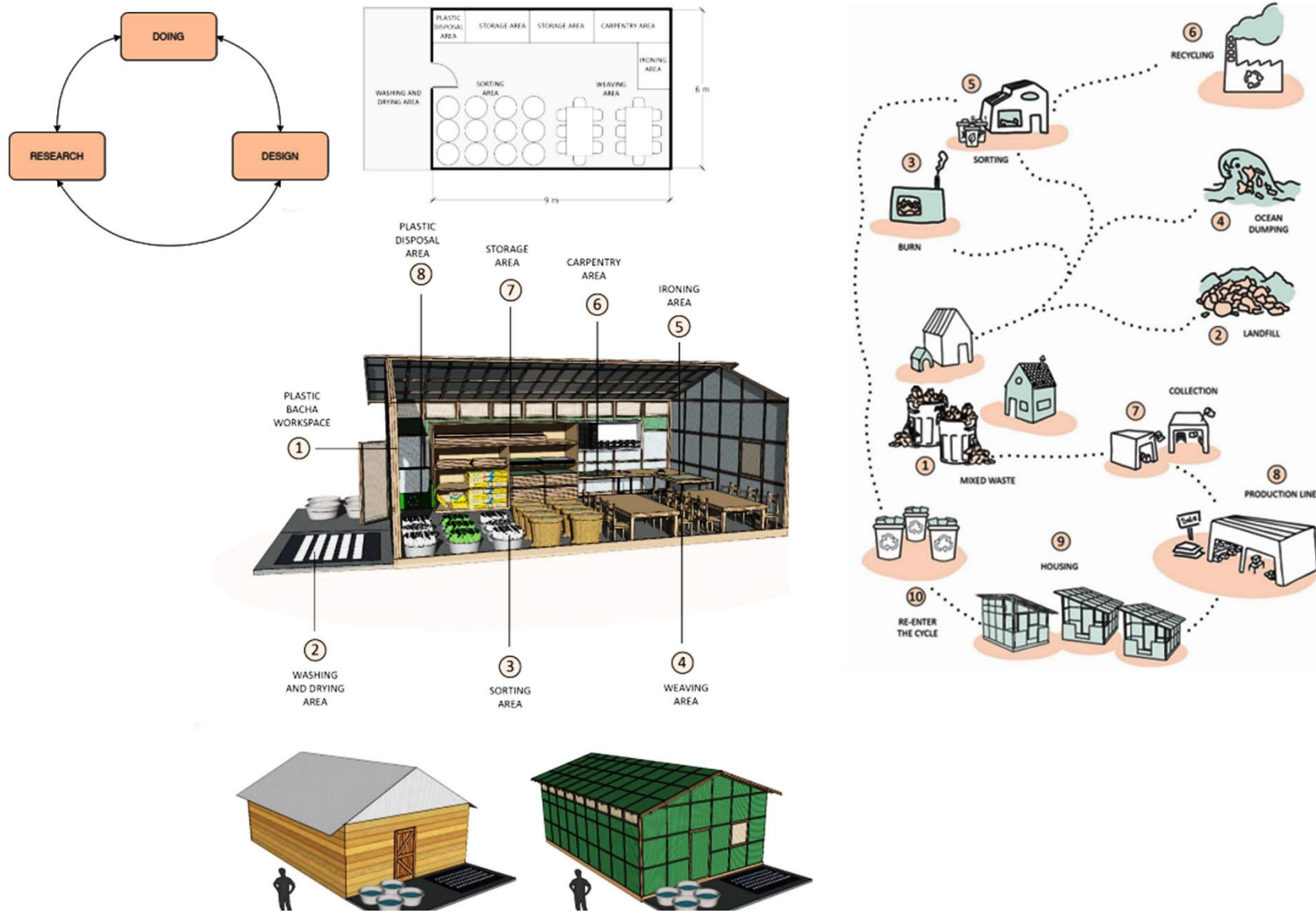


Figure 102 Figure 103 Implementation model Source Author 2023

### 6.3: RECOMMENDATIONS FOR FUTURE RESEARCH

Issue	Description
<p><b>Research and Development Issue</b></p>	<ul style="list-style-type: none"> <li>- <b>Architectural Value:</b> There is a need for more aesthetically designed prototypes and skill development programs to attract the public and the construction industry to use plastic waste as a building material.</li> <li>- <b>Lack of Data:</b> There are many challenges and barriers that prevent the research and innovations in alternative materials and building technologies from reaching the field of applications. There is a need for a robust implementation strategy and simplification of treatment methods to make plastic waste a mainstream building material.</li> <li>- <b>Evolution of Standards:</b> Plastic waste needs more research, testing, and experience to evolve into a standard practice and gain social acceptance, similar to the historical acceptance of steel and concrete as urban materials.</li> </ul>
<p><b>Execution Issues</b></p>	<ul style="list-style-type: none"> <li>- <b>Quality Availability:</b> There is a lack of quality and quantity of plastic waste available for construction, due to poor waste management and collection systems. There is a need for more plastic waste management and recycling plants, as well as incentives and regulations to encourage the use of plastic waste as a building material.</li> <li>- <b>Prefabrication:</b> There is a difficulty in producing, transporting, and installing plastic waste materials, due to the variability and complexity of the material. There is a need for more prefabricated components and kits, as well as modular and flexible design solutions, to facilitate the construction process.</li> <li>- <b>Skillset:</b> There is a lack of skilled and trained manpower for using plastic waste as a construction material, due to the novelty and unfamiliarity of the material. There is a need for more training and guidance programs, as well as awareness and education campaigns, to equip the construction workers and the community with the necessary skills and knowledge.</li> <li>- <b>Testing Problems:</b> There is a lack of standardized and simplified testing and quality control methods for plastic waste materials, due to the lack of data, standards, and technology development. There is a need for more testing and quality control facilities, as well as certification and accreditation systems, to ensure the safety and durability of the material.</li> </ul>
<p><b>Social Issues</b></p>	<ul style="list-style-type: none"> <li>- <b>Affordability:</b> Plastic waste is a cheap and abundant material that can reduce the cost of construction and provide affordable housing solutions for the low-income and vulnerable groups, such as the internally displaced persons (IDPs).</li> <li>- <b>Lifecycle:</b> Plastic waste is a durable and long-lasting material that can extend the lifespan of the buildings and reduce the maintenance and repair costs. However, plastic waste also poses environmental and health risks, such as</li> </ul>

Issue	Description
	<p>leaching of toxic chemicals, emission of greenhouse gases, and accumulation of microplastics. There is a need for more research and innovation on the lifecycle assessment and impact of plastic waste materials.</p> <ul style="list-style-type: none"> <li>- <b>Lack of Awareness/Acceptance:</b> Plastic waste is a stigmatized and marginalized material that faces social and cultural resistance and prejudice, due to the negative perception and association of plastic waste with pollution, poverty, and low quality. There is a need for more advocacy and promotion of the benefits, aesthetics, and sustainability of plastic waste materials, as well as the creation of prototypes and models, to change the attitude and behavior of the public and the construction industry.</li> <li>- <b>Community Engagement:</b> Plastic waste is a material that can foster social cohesion and collaboration, by involving and empowering the community in the production, construction, and governance of the plastic waste materials and buildings. There is a need for more participatory and user-centered design approaches, as well as the facilitation of the exchange of information and knowledge, to create a sense of ownership and identity among the community.</li> <li>- <b>Effective Waste Management:</b> Plastic waste is a material that can provide a solution for the plastic waste disposal problem, by recycling and reusing the plastic waste as a building material. However, plastic waste also requires effective waste management systems, such as collection, sorting, cleaning, and processing, to ensure the quality and availability of the plastic waste materials. There is a need for more waste management and recycling infrastructure, as well as incentives and regulations, to encourage the use of plastic waste as a building material.</li> <li>- <b>Cutting Cost through Technology:</b> Plastic waste is a material that can benefit from the use of advanced technologies, such as computer-aided design, 3D printing, and robotics, to improve the production, transportation, and installation of the plastic waste materials and buildings. There is a need for more research and innovation on the use of technology for plastic waste construction, as well as the accessibility and affordability of the technology for the low-income and vulnerable groups.</li> <li>- <b>Creating Awareness:</b> Plastic waste is a material that can raise awareness and education on the environmental and social issues related to plastic waste, such as pollution, climate change, and displacement. There is a need for more awareness and education campaigns, as well as the integration of plastic waste construction in the curriculum and training programs, to inform and inspire the public and the construction industry about the potential and challenges of plastic waste as a building material.</li> <li>- <b>Mass Production:</b> Plastic waste is a material that can enable mass production and customization of the building components and buildings, due to the availability and variability of the plastic waste materials. There is a need for more standardization and modularization of the plastic waste materials and buildings, as well as the optimization and automation of the production and construction processes, to increase the efficiency and quality of the plastic waste construction.</li> </ul>

Issue	Description
	<p>- <b>Hybrid System:</b> Plastic waste is a material that can be combined with other materials, such as concrete, steel, wood, and bamboo, to create hybrid systems that can enhance the properties and performance of the plastic waste materials and buildings. There is a need for more research and innovation on the compatibility and integration of plastic waste with other materials, as well as the design and engineering of the hybrid systems, to create more diverse and innovative plastic waste construction solutions.</p>
<p><b>Material Issues</b></p>	<p>- <b>Recyclability:</b> Plastic waste is a material that can be recycled and reused as a construction material, reducing the amount of waste going to landfills or littering the environment. However, plastic waste also loses its value and quality every time it is recycled, unless other materials or additives are added to enhance its properties. There is a need for more research and innovation on the recyclability and reuse of plastic waste materials, as well as the development and use of biodegradable and compostable plastics.</p> <p>- <b>Fire Susceptibility:</b> Plastic waste is a material that is susceptible to fire and can emit toxic fumes and smoke when burned. There is a need for more research and innovation on the fire resistance and safety of plastic waste materials, as well as the use of fire retardants and other materials or methods to reduce the fire risk and impact of plastic waste construction.</p> <p>- <b>Structural Compatibility:</b> Plastic waste is a material that has limited structural capacity and compatibility, and may not be suitable for high-rise or heavy-load buildings. There is a need for more research and innovation on the structural properties and performance of plastic waste materials, as well as the use of other materials or methods to increase the strength and stability of plastic waste construction.</p> <p>- <b>Joinery:</b> Plastic waste is a material that has different joinery and connection methods than conventional materials, and may require special tools and techniques to assemble and install the plastic waste materials and buildings. There is a need for more research and innovation on the joinery and connection methods of plastic waste materials, as well as the development and use of simple and user-friendly tools and techniques for plastic waste construction.</p>

#### 6.4: PERSONAL REFLECTIONS

This research was motivated by personal interest and passion for finding creative and sustainable solutions for the urban challenges in the developing world. It was inspired by the examples of other architects and designers who have used waste as a resource for innovation and transformation. It was also moved by the plight and the resilience of the people living in the IDP camps, who have faced displacement, violence,

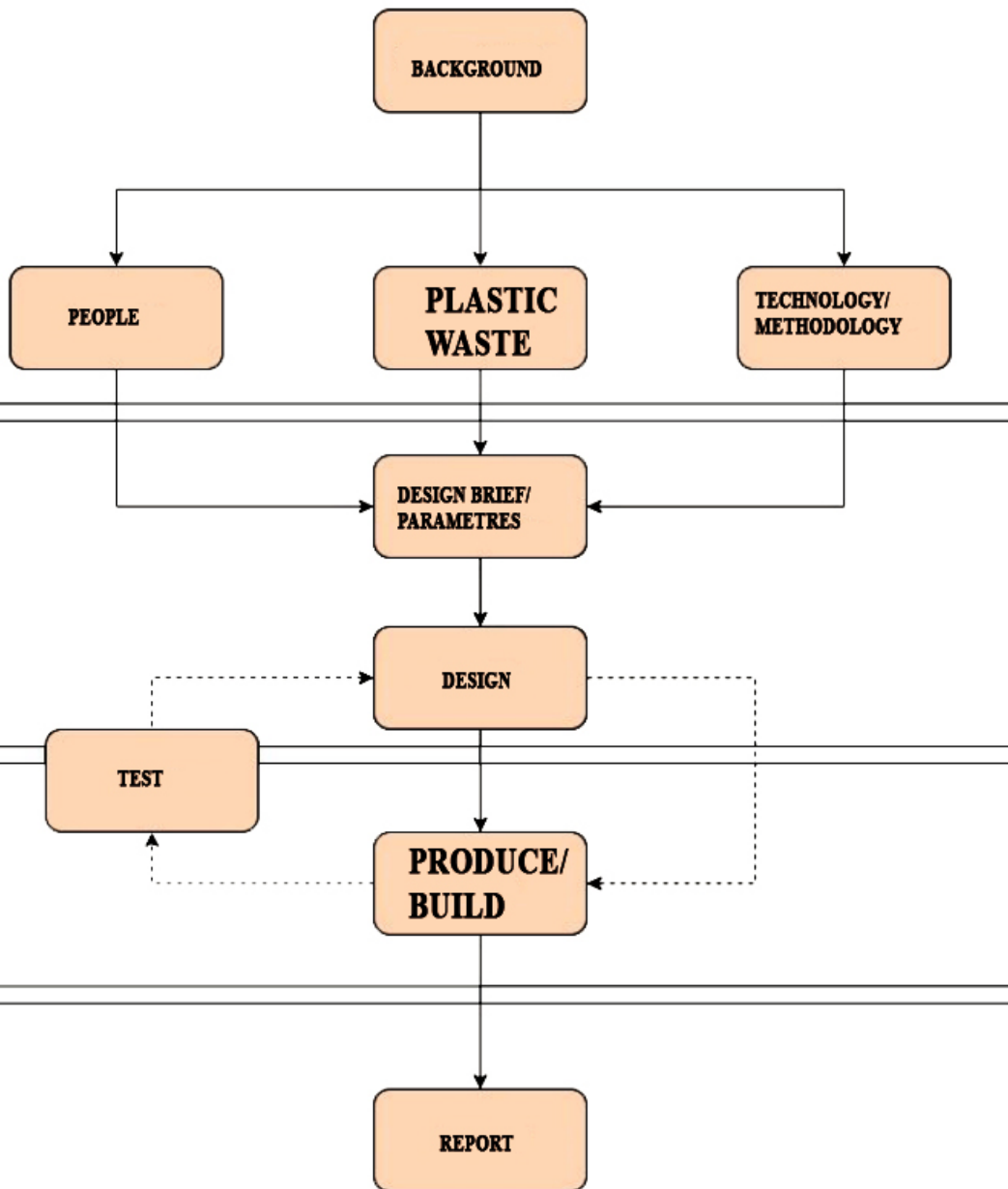


Figure 104 Research Plan Source Author 2023

and poverty. The paper aimed to explore how architecture and design can make a positive difference in their lives as well as the environment facing a great pollution crisis.

The research provided lessons, both academically and personally. It has ensured a gain in new knowledge and skills in the field of architecture and urban design, as well as in the field of plastic waste management and recycling. A critical and reflective attitude towards personal work and the work of others has been developed. There were challenges and difficulties during this research, such as finding reliable data, conducting fieldwork, testing the products, and balancing fieldwork with documentation of the thesis. However, there were many enjoyable, rewarding and fulfilling moments, such as meeting and working with the circular economy and climate change community at forums, stakeholders during fieldwork, seeing the results of the experiments and finally presenting the findings and the proposals.

The paper is a pre-amble to the anticipated implementation of the design proposal with the guidelines garnered from the research. The design project will not only provide a practical and viable solution for the housing and the environmental issues in the region, but also inspire and empower the people to take climate action and to improve their own situations. The project has the potential to create a positive impact and a lasting change in the community and the society.

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## 6.5: CONCLUDING REMARKS

The thesis has explored the opportunities and limitations of using plastic waste as a construction material for building blocks, tiles, and roofs in Kenya. It has presented a comprehensive study of the technical, social, economic, and environmental aspects of this innovative and sustainable approach to address the housing crisis and the environmental degradation caused by plastic pollution. I have also proposed an implementation strategy through a design proposal model which can accommodate the production and distribution of the plastic building component, which involves the participation and empowerment of the local communities living in the residential zones near Ngong Dumpsite in Kajiado, Kenya. It has also shown how the plastic building component can be used to construct various types of structures, such as shelters, schools, clinics, and community centers, that can improve the living conditions and the well-being of the people.

On the other hand, the paper also acknowledges the challenges, opportunities, and limitations of using plastic waste as a construction material. It has discussed the issues of quality, durability, safety, aesthetics, and perception that may affect the acceptance and adoption of this alternative building system. It has identified the gaps and the areas that need further research and development in this field. Some recommendations for improving the performance, the design, and the implementation of the plastic building component, as well as for enhancing the awareness, the education, and the policy support for this initiative have been suggested in the paper.

In conclusion, this thesis has made a significant contribution to the field of architecture and urban design by demonstrating that waste is not a problem, but a potential. By exploring the use of plastic waste as a building material in Kenya, this study has shown that innovative solutions can be found in unlikely places. The findings of this research have implications for the promotion of social and environmental justice, and the creation of sustainable and resilient communities. As the author notes, 'In waste, we you will find the blueprint of tomorrow's architecture.' This thesis provides a framework for using plastic waste as a construction material, based on the principles of circular economy and waste management. It also showcases some of the potential applications and benefits of using plastic waste as a construction material for various sectors and stakeholders. The author hopes that this study will inspire further research and practice in this field, and contribute to the creation of a more sustainable and equitable future.

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## APPENDIX 1- DATA COLLECTION TOOLS

### SEMI STRUCTURED INTERVIEW-STAKEHOLDERS

Hello, my name is  Maryam Wangeshi a final year student from \_\_\_\_\_Department of Architecture Kenyatta University\_\_\_\_\_. I am conducting a study on building from solid waste in Kenya. I would like to interview you on your opinions and feedback on building from plastic waste in Kenya. The interview will take about 30 minutes to complete. Your responses will be anonymous and confidential. Your participation is voluntary and you can withdraw at any time. This information collected is purely for educational purposes only.

Do you consent to participate in this interview?

Yes

No

(If yes, proceed with the interview. If no, thank them and end the interview.)

#### **PART A**

Thank you for your consent. I will start by asking you some general questions about yourself and your house. (Specific to occupants of the house)

1.How long have you been living in this house?

2.How many people live in this house with you?

3.What are the main reasons why you chose to live in this house?

#### **PART B**

Now I will ask you some specific questions about the quality and performance of this house.

1.How do you rate the strength and durability of this house, compared to conventional houses made from natural materials, on a scale of 1 to 5, where 1 is very poor and 5 is excellent?

2.How do you rate the water resistance and fire resistance of this house, compared to conventional houses made from natural materials, on a scale of 1 to 5, where 1 is very poor and 5 is excellent?

3.How do you rate the thermal insulation and sound insulation of this house, compared to conventional houses made from natural materials, on a scale of 1 to 5, where 1 is very poor and 5 is excellent?

4.How do you rate the aesthetic appeal and design of this house, compared to conventional houses made from natural materials, on a scale of 1 to 5, where 1 is very poor and 5 is excellent?

#### **PART C**

Now I will ask you some specific questions about the environmental and social impact of this house.

1.How do you perceive the environmental impact of building this house using recycled plastic bricks, compared to building conventional houses using natural materials, on a scale of 1 to 5, where 1 is very negative and 5 is very positive?

2.How do you perceive the social impact of building this house using recycled plastic bricks, compared to building conventional houses using natural materials, on a scale of 1 to 5, where 1 is very negative and 5 is very positive?

## OPEN ENDED QUESTIONNAIRE-GJENGE MAKERS

- What is the background and motivation of starting Gjenge Makers?
- What are the products and services that Gjenge Makers offers?
- How do you produce the building materials from plastic waste?
- What are the technical specifications and characteristics of the building materials from plastic waste?
- What are the advantages and disadvantages of the building materials from plastic waste compared to the conventional building materials?
- What are the challenges and risks that you face in the production and operation of Gjenge Makers?
- How do you overcome and manage these challenges and risks?
- What are the benefits and impacts that Gjenge Makers creates for the environment, the society, and the economy?
- How do you measure and evaluate these benefits and impacts?
- What are the goals and vision of Gjenge Makers for the future?
- What are the opportunities and threats that Gjenge Makers faces in the market and the industry?
- How do you seize and exploit these opportunities and cope and survive these threats?
- What are the stakeholders and partners that Gjenge Makers works with or plans to work with?
- How do you collaborate and communicate with these stakeholders and partners?
- What are the policies and regulations that affect Gjenge Makers and the building from plastic waste sector?
- How do you comply and influence these policies and regulations?
- What are the best practices and innovations that Gjenge Makers adopts or develops in the building from plastic waste sector?
- How do you learn and improve these best practices and innovations?
- What are the research and knowledge gaps that Gjenge Makers identifies or fills in the building from plastic waste sector?
- How do you conduct and disseminate this research and know

## SITE PHOTOGRAPHS



Figure 105 Site study pictures. Source Author 2023

## SECONDARY DATA ON GJENGE MAKERS

Source	Title	Description	URL
UNEP	Gjenge Makers: Building from plastic waste in Kenya	A video that showcases the story and impact of Gjenge Makers, featuring an interview with Nzambi Matee and some of the workers and customers.	[1]
CNN	She turns plastic waste into bricks that are stronger than concrete	An article that profiles Nzambi Matee and Gjenge Makers, highlighting the innovation and inspiration behind the enterprise and its products.	[2]
BBC	The woman who makes bricks from plastic waste	An article that describes the production process and the social and environmental benefits of Gjenge Makers, featuring some facts and figures about the enterprise and its products.	[3]
Arch Daily	How Recycled Plastic Bricks Are Building New Futures in Kenya	An article that analyzes the technical and architectural aspects and implications of Gjenge Makers, featuring some examples and images of the buildings that use the products.	[4]
Forbes	Meet The Young Female Engineer Who Is Building Kenya with Recycled Plastic Bricks	An article that explores the business and leadership challenges and opportunities of Gjenge Makers, featuring some insights and advice from Nzambi Matee and some of the stakeholders and partners.	[5]

1. -<https://www.gjenge.co.ke/>
2. -<https://www.builtinafrica.io/videos/gjenge-makers>
3. -<https://engineerdeedee.com/gjenge-makers/>
4. -<https://phys.org/news/2022-03-trash-kenyan-inventor-plastic-bricks.html>
5. -<https://www.designboom.com/technology/gjenge-makers-recycled-plastic-bricks-kenya-02-08-2021/>

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