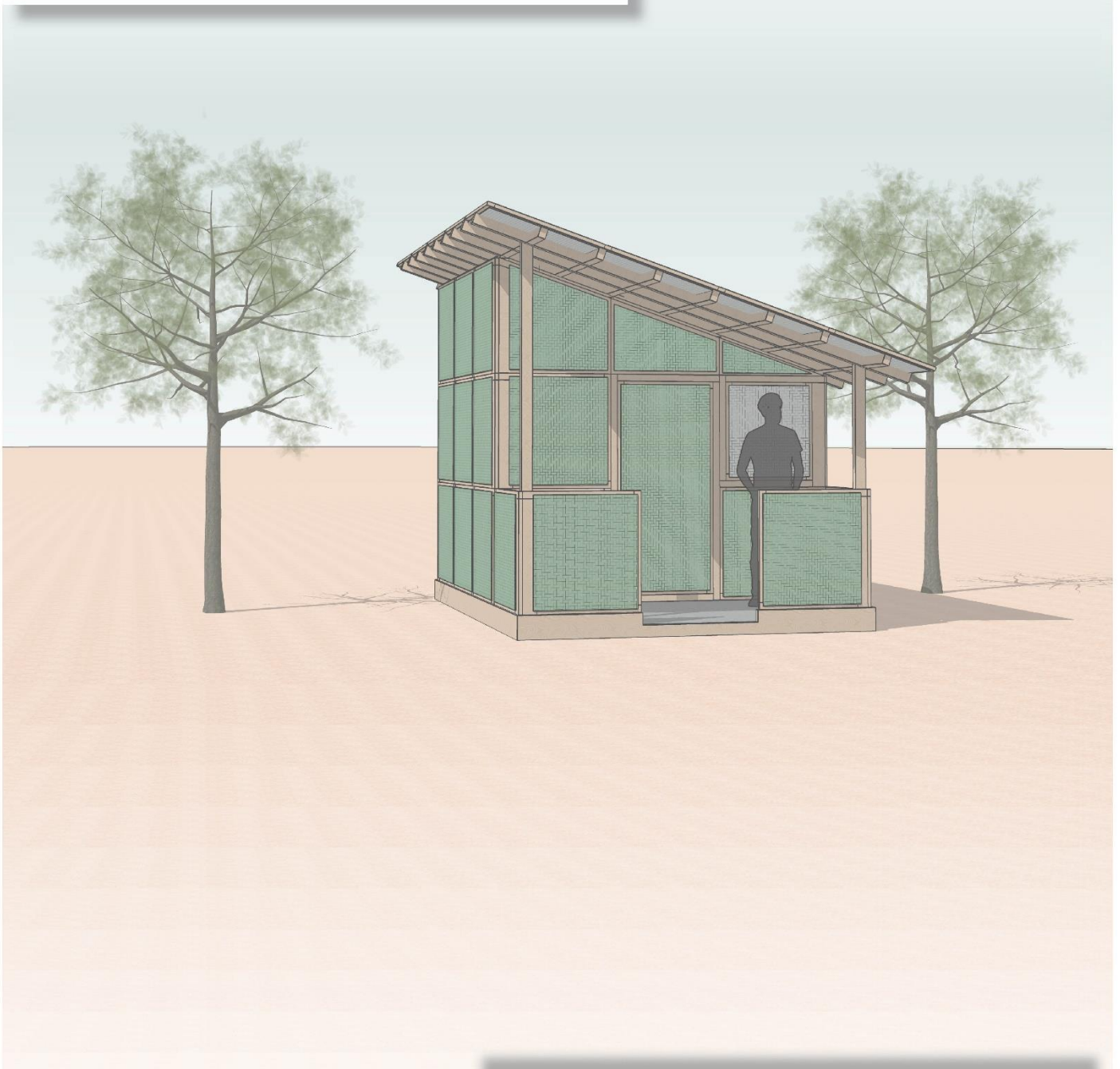


REUSE OF PLASTIC AS A BUILDING PRODUCT

Recycling plastic waste into a low-cost building component for internally displaced persons (IDP) camp resettlement housing in Nigeria



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PREFACE

This report encompasses a graduation project submitted to fulfil the requirements for the title of Master of Science at the Faculty of Architecture and the Built Environment, Delft University of Technology. This research was conducted to find an alternative use for waste plastic as building components, specifically for the residents of an IDP camp within the federal capital territory of Nigeria, Abuja.

This journey began before I attended the TU. Delft. I visited an Internally Displaced People's Camp in Abuja as part of a medical outreach programme. The condition in which the residents lived really alarmed me, and I sought a master's degree whereby I could potentially design a realistic system to help improve these people's lives. This situation was a significant motivation for a building technology master's degree. Shelter is a fundamental human right, and everyone deserves to have a home that gives them safety and comfort. Humans have created a consumption-driven system that widens the divide between very low-income earners and the rest of society. Thus, the housing systems used in these camps are of the lowest quality.

Another problem facing the country is plastic waste. Plastic waste is a global problem that is particularly evident within Nigeria. Without a proper large scale waste management system, the plastic ends up in water bodies or landfills and contributes to environmental degradation. Therefore, strategies for recycling plastic effectively and efficiently need to be developed. This research aims to provide a possible solution for both issues.

Although the materials used for the housing are of low quality, the residents themselves are pretty resourceful in terms of adapting their resources to suit their needs, efficiency of building techniques and spatial arrangements. Therefore, they serve as an essential knowledge source to derive recycling methodologies for sustainable building.

A standardised system for building components from plastic waste is designed and developed within this research. These building components require low-income technology for production, and the camp residents could use them to generate income for the IDP camps and low-income earners. The findings within this report will be based on literature research, testing and on-site analysis of an IDP in Abuja and with a specific focus on the Kuchingoro IDP camp in Abuja, Nigeria.

ACKNOWLEDGEMENT

My profound gratitude goes to the Almighty Allah, who has granted me the wisdom, understanding, and the opportunity to write this work. I would also like to acknowledge with gratitude the willing cooperation and assistance of Dr Ing. Marcel Bilow. His enthusiasm and knowledge, especially on the practical aspect of architecture, truly inspired me to approach this graduation topic as a hands-on build and design project. I was able to develop inventive ways to solve a problem while designing something that can be put into practice under his expert supervision. Secondly, I would also like to thank Dr ir. F.A. Veer for providing extensive insight into the material properties of the plastics used for the design. His immense knowledge of material science helped me to make decisions more accurately and concisely. His straightforward and expert guidance made the material design aspect most enjoyable. Thank you for also assisting with testing the mechanical properties and the quality of the plastic component designed.

I would also like to thank Hajara Iyal for steering me towards reusing waste materials for design as a possible thesis topic. Our conversations were always insightful, and she helped give me clarity very early on in my thesis journey, so I am most grateful. I want to express my appreciation to Mrs Intissar Bashir Kurfi, who took the time to answer my questions regarding her plastic brick business and her experiences in the Nigerian market. I would also like to thank my friend and fellow coursemate Beza, who provided the much-needed support throughout the eight months of writing this thesis, including the time in the COVID-19 lockdown. It was challenging to say the least, but I am glad we went through the process together. I also want to thank Kuchingoro camp residents Mr Luka Yathuma, Elizabeth Pilimo, Naomi Yohanna, John Nuhu and Yohanna Ishaku. They welcomed me into their community and took the time to answer all my questions regarding their day-to-day lives and living situations, and for that, I am most grateful. Thank you to all my friends who also offered support and encouragement in their unique ways during this period.

Last but not least, I would like to thank my family for their support and their encouragement. Thank you for always indulging my multiple requests no matter how tasking, including flying cement bags from Nigeria for testing and even making prototypes. You all support my endeavours most wholeheartedly, and I am indebted to you all for that indeed.

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1

Research Definition



1.1 Introduction

The drivers of internal displacement of people in Nigeria are complex, multi-faceted, and sometimes overlap. They arise as a result of political, ethnic and most notably religious conflict. Every year, thousands of people are displaced from their homes due to natural disasters such as erosion of flooding in the West and Northern regions, oil exploration projects in the South-South region, oil spillage in the east. (National Legislative Bodies / National Authorities, 2012). From 2014, the foremost cause of displacement of people is the rise in terrorism, particularly in the north-eastern region of Nigeria. The militant Islamist group Boko haram wreaks havoc on the local communities (IDMC, 2020). This conflict has caused people to flee to major cities within the country. A total of 2.6 million people live in displacement camps as of 2019 (IDMC, 2020).

Shelter is one of the basic needs of human beings, especially those seeking refuge. Due to the destruction of the initial shelters of internally displaced persons, it becomes one of the primary necessities which they require desperately. Consequently, the government, NGO's as well as foreign organisations from different nations actively seek to provide shelter for Internally Displaced Persons. However, the response to shelter provision shortage in Nigeria is either non-existent, slow, or inadequate (Crisp and Mooney, 1998). According to the National Policy on Internally Displaced Persons (IDPs) in Nigeria, 2012, the Nigerian government generally prioritises disaster-induced displacement over conflict-induced displacement. This approach has led to the lack of strategic housing frameworks for the IDP camps within Abuja. Therefore, there is a need to provide a solution that is durable and sustainable.

The arrival of IDPs in a community also adds additional strain on the resources of the host communities as these people are mainly unemployed. The host community does not always receive adequate governmental and humanitarian assistance, leading to insecurity and tensions between both groups.

The accommodations within these camps are in terrible shape, with residents living in tents or makeshift shelters built with recycled materials. There is little to no security, and the structures are not suitable enough for housing, neither are they ideal for other facilities such as schools. As a result of increased people on land, this also increases waste pollution, which includes both human and plastic waste. Plastics are already posing a global problem and are available in the form of bottles, packaging and many others. There is little to no waste management in these IDP camps as most waste products are either used to create makeshift tents or burned. What if there is a way to recycle or re-use this commonly discarded or burned plastic to create a suitable building system for temporary shelter?

1.2 Problem statements

- There is a general lack of sustainable building methods for temporary IDP settlement housing built by low-income earners within the Federal Capital Territory (Abuja), Nigeria. The amount of Internally Displaced Persons within the city is projected to rise within the coming years; therefore, a solution to the housing shortage needs to be developed.
- Nigeria is located in a tropical region; the global threat of climate change will lead to increased extreme weather conditions. The low-income earners within these camps will be the most vulnerable due to the materials used for makeshift temporary construction.
- The cohabitation of IDPs and host communities leads to increased tensions within the camp, and this also leads to security problems.

- One of the significant global environmental challenges facing our world today is the menace of plastic waste pollution. Plastic is a non-biodegradable material which causes environmental hazard on both land and sea. Nigeria is one of the primary importers of plastic into the African continent; this plastic waste has led to a rapid increase in environmental pollution. One of the most significant challenges in Nigeria is waste management. According to research, most of these wastes are plastics and polymers, which are challenging to manage because they are non-biodegradable. Additionally, less than 12% of plastic in Nigeria are recycled, with about 80% ending up on dumpsites or landfills. Therefore, there is a real need for the building industry to find an alternative use to these plastic wastes.
- The existing camps are usually constructed using recycled waste materials, including plastics, thus increasing single-use products' life cycle. The recycling of non-biodegradable waste products should not be in direct competition with the design solution, even if it results from economic poverty. Thus, building materials should complement the recycling nature of these camps.

1.3 Research objective

The general objective of this research is to improve the living conditions of an IDP camp called Kuchingoro located within the Federal Capital Territory (Abuja), Nigeria, by making a building component made out of plastic waste.

Within the boundaries of this research, sub-objectives are:

- Providing a working system for IDPs, which may help them earn a living.
- Gain knowledge from local building technology
- Design with climatic conditions as a consideration
- Develop a sustainable alternative for utilising plastic waste.

This research is to be conducted within eight months. The outcome of this paper will be a comprehensive design brief that provides an appropriate design suitable for the context. The design should be able to be created and tested by one student.

1.4 Research questions

Having described the subject and objectives, the next step is to formulate the main research question.

"How can waste plastic materials be recycled to make temporary low-cost building components that improve the living conditions of IDPs in Nigeria? "

The research is comprised of various stages, further elaborated on in the subsequent paragraph: Research methodology. The first stage, which is the exploring stage, will have the following sub-questions:

- i. Background

What is the geographical context of Abuja?

What are the climatic conditions of Abuja at present and in the immediate future? What are IDP camps, and what are the official housing policies regarding them?

ii. Local People

What is the existing condition of the Kuchingoro IDP camp?

What do the people living within these camps require in terms of housing facilities?

iii. Technology

What are the existing building methods within the IDP camps?

What resources and products are locally available?

Are other low-cost housing options available?

iv. Plastic

What are the general plastic statistics within Nigeria, and are they suitable enough for projected housing?

What kind of plastic is suitable and available to create building components?

What are the local initiatives created to tackle plastic pollution?

What precedents/ techniques have been used to create building components from recycled waste plastic?

1.5 Research methodology

This research consists of four main stages, namely:

i. The exploration stage:

The exploration stage involves deep research into the local context and existing methods for waste recycling, culminating in creating a design brief. This research includes literature study, site visits and interviews. The on-site visit is essential in order to:

Experience IDP camps and the surrounding context in real-life

Validate initial literature research.

Get additional information and determine what the people need directly.

In-person interviews are conducted with specific people to get accurate information and gather essential on-site information.

The research results culminate into a specific set of requirements upon which the design is based.

ii. The design stage:

The set of requirements derived from the exploration stage will serve as the starting point for this phase. The product design will involve constant development while consulting with mentors, the possible users of the product and professionals. The end goal will be a set of drawings that can be utilised for the final phase.

iii. The experimentation stage:

This stage will involve physical testing of the design to ensure its validity and application in a real-life context. A physical model can be created and tested. This stage will help fine-tune the prototype because if any problems are encountered, the design brief or the design itself is adjusted accordingly. This process results in a circular process until the list of requirements and the products align.

iv. The evaluation stage:

The evaluation is the final stage which is the report writing and development of the product. This stage concludes with a proper design brief and instructions on building and assembling the building component. The developed component and the existing building component are compared based on material properties. However, a complete evaluation can only be possible if the element is applied in the camp and studied over time, which is outside the scope of this research.

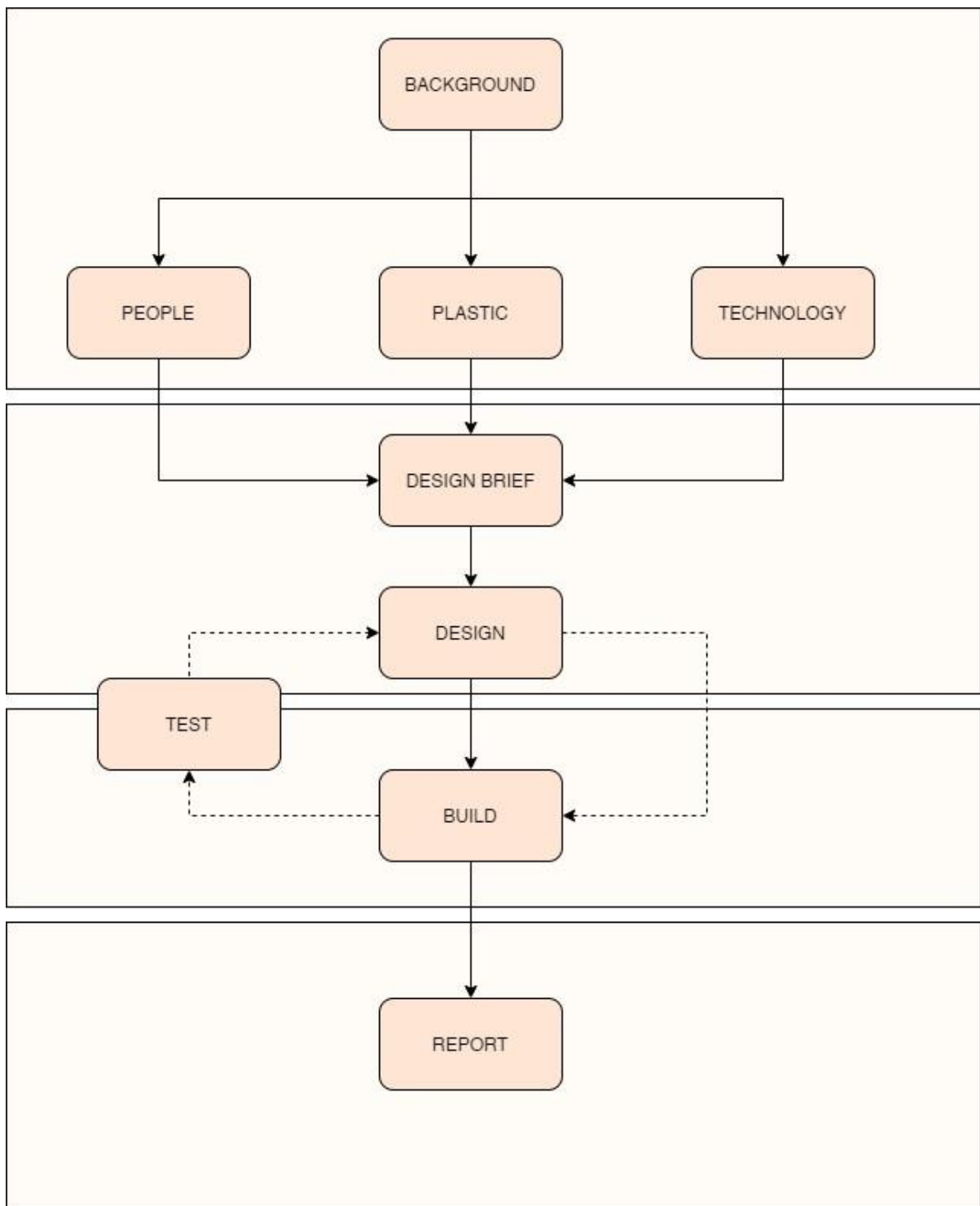


Figure 1: Research Framework

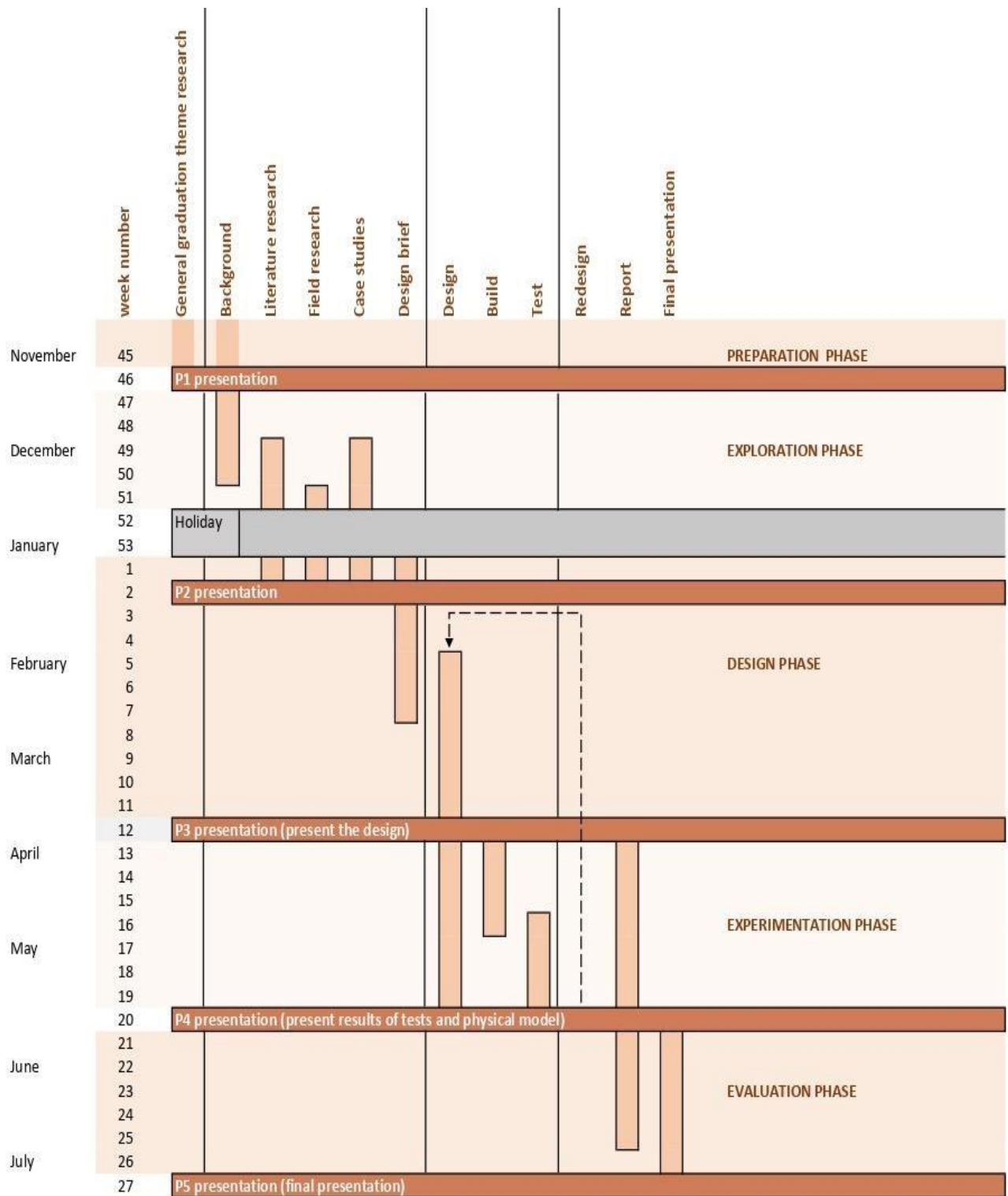


Figure 2: Research Plan

1.6 Definitions

a. IDP:

Internally displaced persons (IDPs), according to the United Nations Guiding Principles on Internal Displacement, are "persons or groups of persons who have been forced or obliged to flee or to leave their homes or places of habitual residence, in particular as a result of or to avoid the effects of armed conflict, situations of generalised violence, violations of human rights or natural or human-made disasters, and who have not crossed an internationally recognised state border." (Handbook for the Protection of Internally Displaced Persons, 2010).

Although this definition is extensive and internationally recognised, it does not assign a special legal status to internally displaced persons; thus, it is only descriptive. This lack of recognition stems from the fact that IDPs remain within the country and are still entitled to all the rights and guarantees as habitual residents and citizens of their countries. Therefore, the national authorities are required to protect the IDPs' rights and take measures to prevent the forced displacement of citizens.

b. Building component:

Building component According to the NEC, any subsystem, subassembly, or other system designed for use in (or integral with) a structure or part of a structure, which can include electrical, fire protection, mechanical, plumbing, and structural systems and other systems affecting health and safety (McGraw-Hill Dictionary of Architecture and Construction. (2003). However, within this research, 'building component' is defined as any module which can be used repetitively as a building material, functioning as either a structural material or cladding material.

c. Camps:

These are erected sites with non-permanent shelters (e.g., tents) used for evacuated or displaced persons' collective and communal accommodation. Camps can either be planned (i.e., purposely built sites, completed before or during the influx) or self-settled (i.e., set up spontaneously by internally displaced persons or host communities without the support of the government or the humanitarian community). (National Legislative Bodies/National Authorities (2012)

d. Self-settled Camps:

This is particularly the case when a displaced community settle in camps independent of government or private support. Self-settled camps are often sited on vacant state-owned, private or communal property. (Enwerekowe & Ibrahim, 2019)

e. Planned Camps:

They provide accommodation on sites specifically set up for displaced persons. They usually possess full infrastructural facilities such as water supply, food and non-food item distribution, education and healthcare. (Enwerekowe & Ibrahim, 2019)

f. Conflict-Induced Displacement:

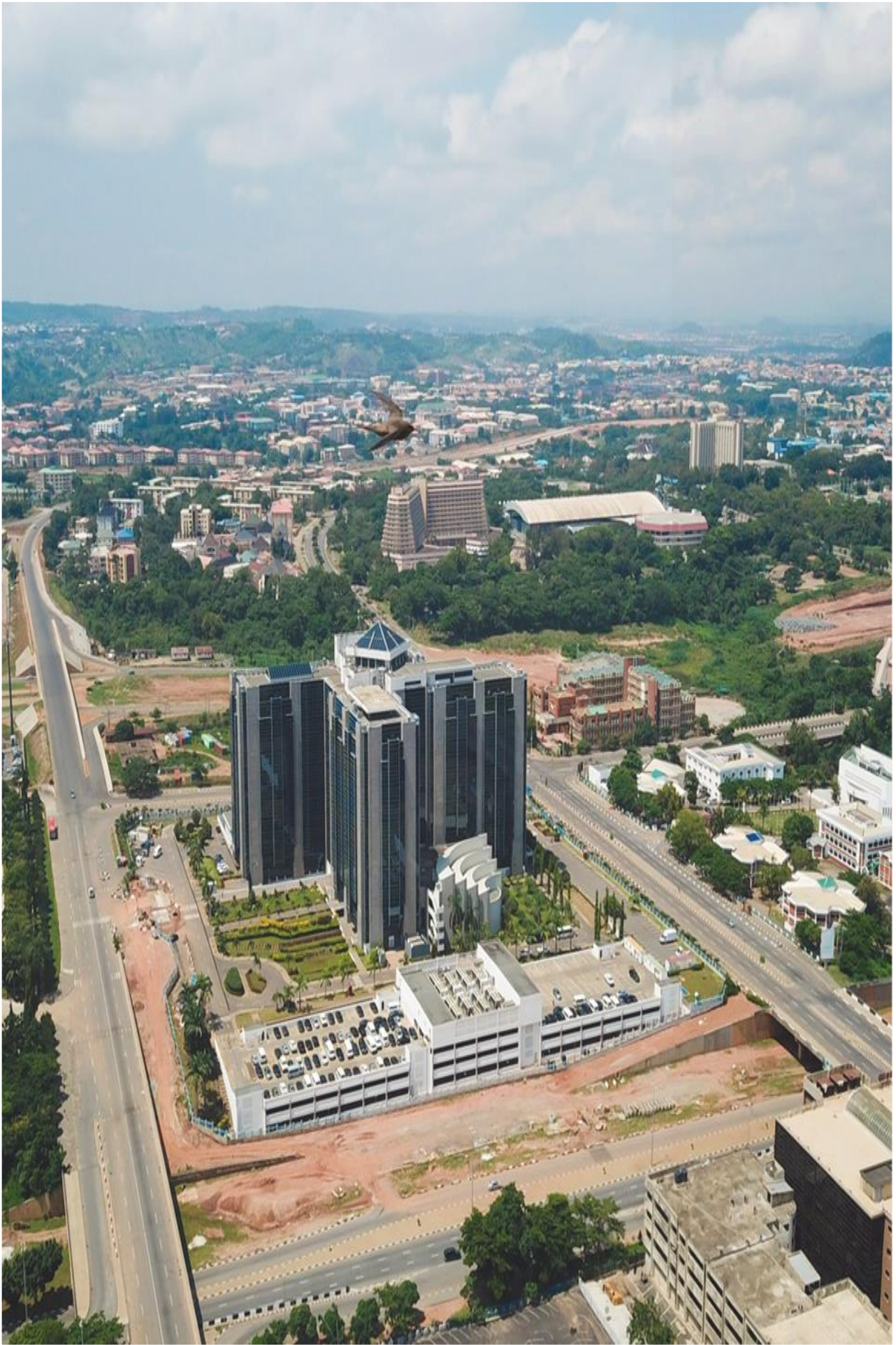
This refers to displacement resulting from people being forced to flee their homes for one or more reasons, including armed conflicts such as civil war, communal conflicts and generalised violence. The state authorities are unable or unwilling to protect them. (National Legislative Bodies / National Authorities, 2012).

1.7 Scope and limitations

- There are IDP camps located all over the country; however, due to insecurity, only one IDP camp is visited. This on-site visit forms the general basis for the design. The camp is the New Kuchingoro IDP camp located in the Kaura region of the Federal Capital Territory of Nigeria, Abuja.
- Plastic waste statistics are not highly accurate in the year this thesis is written (2020/2021); therefore, some assumptions are made.
- As the IDP camps consist of low-income earners, low running costs and investments are restrictions that need to be considered in the final design.
- A complete design evaluation is outside the scope of this study, as the building component will have to be used for at least a year to see how durable and practical it is.
- The assumption is that simple methods are used to reprocess plastic waste. Therefore, the end products material properties might be affected. During the design process, this needs to be taken into account.
- This research was undertaken during the covid-19 pandemic this making access to the faculties limited. As a result, most of the prototyping was carried out in a home setting.

2

Introduction to a
foreign background



2.1 Introduction

While developing a design for a particular place, it is important to carry out extensive research and analysis to understand the regional context of the area. Therefore, this chapter will provide answers to the sub research questions earlier stated in the preceding chapter:

What is the geographical and demographical context of Abuja?

To answer this question, Nigeria is considered at a national scale, then further into the Federal Capital Territory, Abuja.

What are IDP camps, and what are the official housing policies regarding them?

This involves a comprehensive account of IDP camps, the types of IDP camps, the number of IDP camps within Abuja and the official government policies regarding their creation.

What are the climatic conditions of Abuja at present and in the immediate future?

The general living comfort of human beings is often determined or dictated by the climate of the region. Both the outdoor and indoor climate have to be assessed and considered while designing to improve the living conditions of the people for the present day and future use. This chapter will elaborate upon essential weather factors and their effects on the built environment.

2.2 Geographic & Demographics

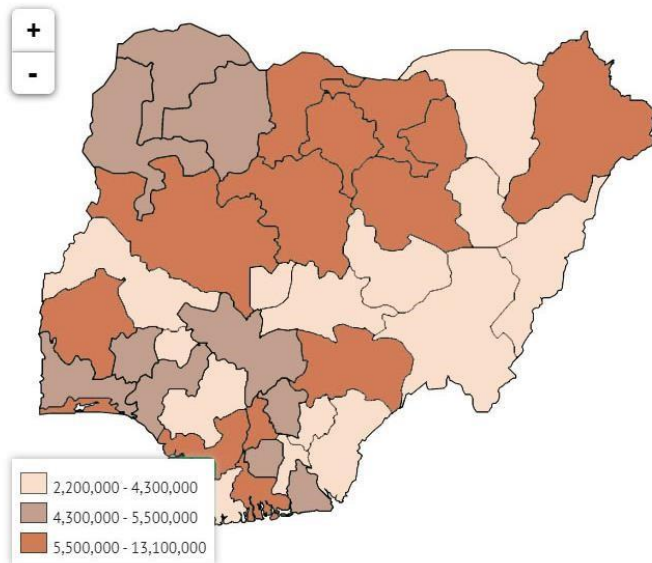
2.21 Nigeria

Nigeria, characterised officially as the Federal Republic of Nigeria, is a West African sovereign country bordering Benin in the west, Niger in the North, Chad in the northeast and Cameroon in the east. It is a federal republic encompassing thirty-six states with more than 250 ethnic groups and various cultures. The national capital of Nigeria is Abuja, in the Federal Capital Territory established by law in 1976 (Reuben, K. U et al. 2020).

Nigeria is a diverse multinational country populated by over 250 tribes speaking 500 distinct languages, all identifying with various cultures. Over 60% of the total population comprises the three main ethnic groups: The Yorubas in the West, the Hausa-Fulani in the North, and the Igbo in the east. The official language chosen to ensure linguistic harmony is English. Nigeria is separated approximately in half between Christians, who live primarily in the south and Muslims, who live mainly in the North. Nigeria has the world's sixth-largest Christian population and fifth-largest Muslim population and, with a minority practising indigenous religions native to their particular ethnic groups. According to the national census conducted in 2006, Nigeria had a total population of about 160 million people; however, in 2020, it has increased to over 200 million and is still projected to grow within the foreseeable future. (State Population, 2006 - Nigeria Data Portal, 2020).

Total Population

Persons



Nigeria Urban vs. Rural Population from 1955 to 2020

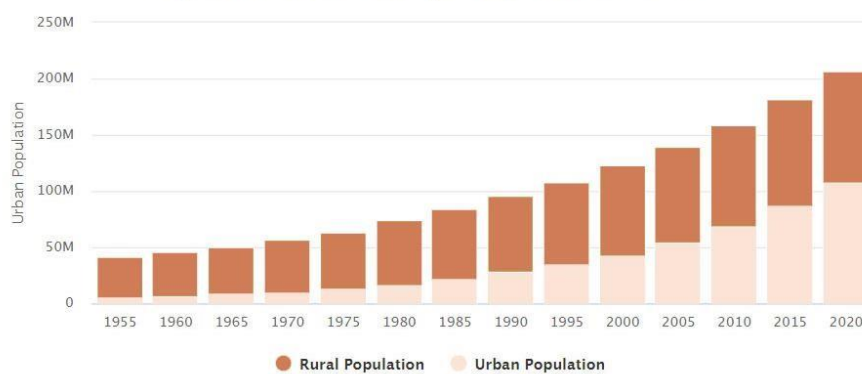


Figure 3: Nigerian Population distribution. (Nigeria Data Portal, 2020)

2.22 Abuja

The Federal Capital Territory, generally known as FCT, or FCT-Abuja, is a federal territory located in the middle belt of Nigeria, more specifically known as the central region. The city of Abuja is situated in this territory, and it is the capital of Nigeria. Lying between latitude 8.25 and 9.20 north of the Equator and longitude 6.45 and 7.39 east of Greenwich Meridian, The Federal Capital Territory has a landmass of approximately 7,315 km². It is situated within the Savannah region with moderate climatic conditions. The Federal Capital Territory was established from segments of Plateau, Niger, old Kwara, and Kaduna States, with the majority of landmass taken from Niger State in 1976. The territory is located above the intersection of the rivers Niger and Benue. The states of Kogi border it to the southwest and North, Nasarawa to the east, Kaduna to the northeast, and south and Niger to the west. An elected governor leads all other states, but the Federal Capital Territory Administration governs Abuja. This FCT Administration is led by a minister whom the President of Nigeria appoints. While the Federal Capital Territory Administration governs the whole of the FCT, the Federal Capital Development Authority (FCDA) exclusively manages the infrastructural and development of the territory.

Given that it is the administrative capital of Nigeria, the city is the location of various embassies and governmental institutions. The Federal Capital territory is currently made up of six area councils, Abaji, Abuja

Municipal Area Council, Bwari, Gwagwalada, Kuje, and Kwali. The capital city Abuja is located inside the wider Abuja Municipal Area Council.

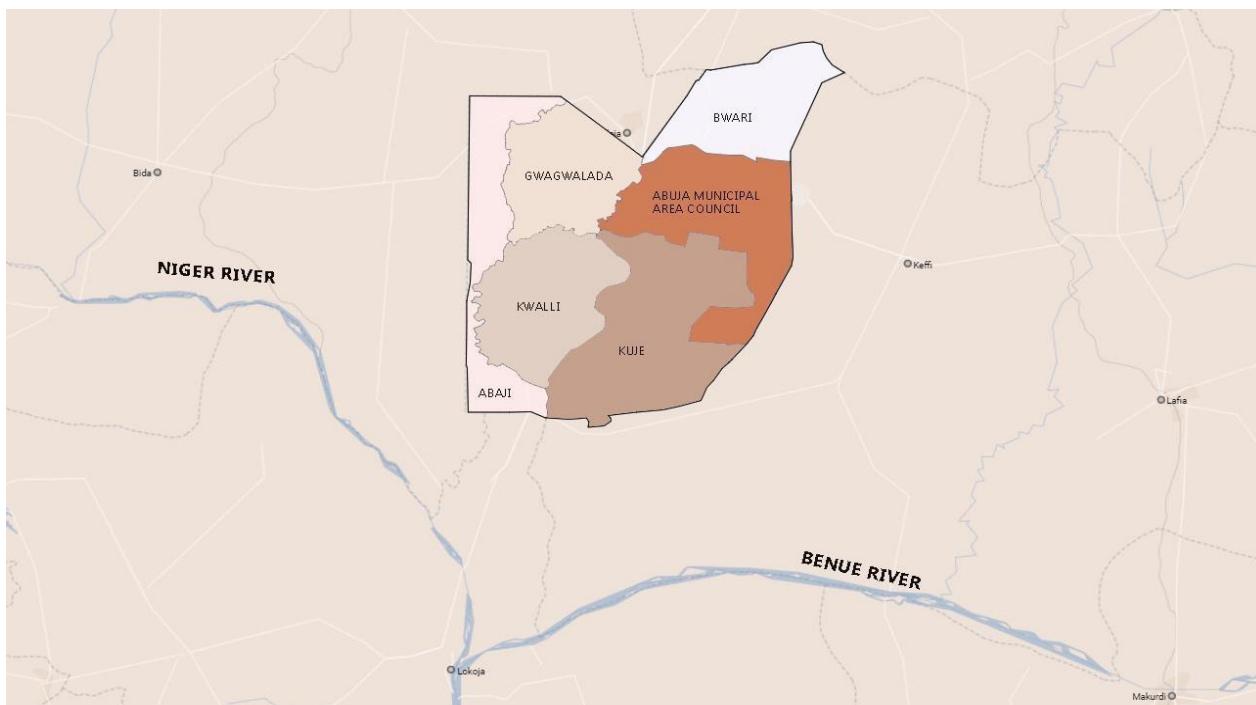


Figure 4: Map of FCT showing the six area councils. (City population.de, 2020)

Name	Status	Population	Population	Population
		Census	Census	Projection
		26/11/1991	21/03/2006	21/03/2016
Federal Capital Territory (Abuja)	Territory	371,674	1,406,239	3,564,100
Abaji	Local Government Area	21,081	58,642	148,600
Abuja Municipal Area Council	Local Government Area	...	776,298	1,967,500
Bwari	Local Government Area	...	229,274	581,100
Gwagwalada	Local Government Area	...	158,618	402,000
Kuje	Local Government Area	44,338	97,233	246,400
Kwali	Local Government Area	...	86,174	218,400

Table 1: Population distribution of FCT. (City population.de, 2020)

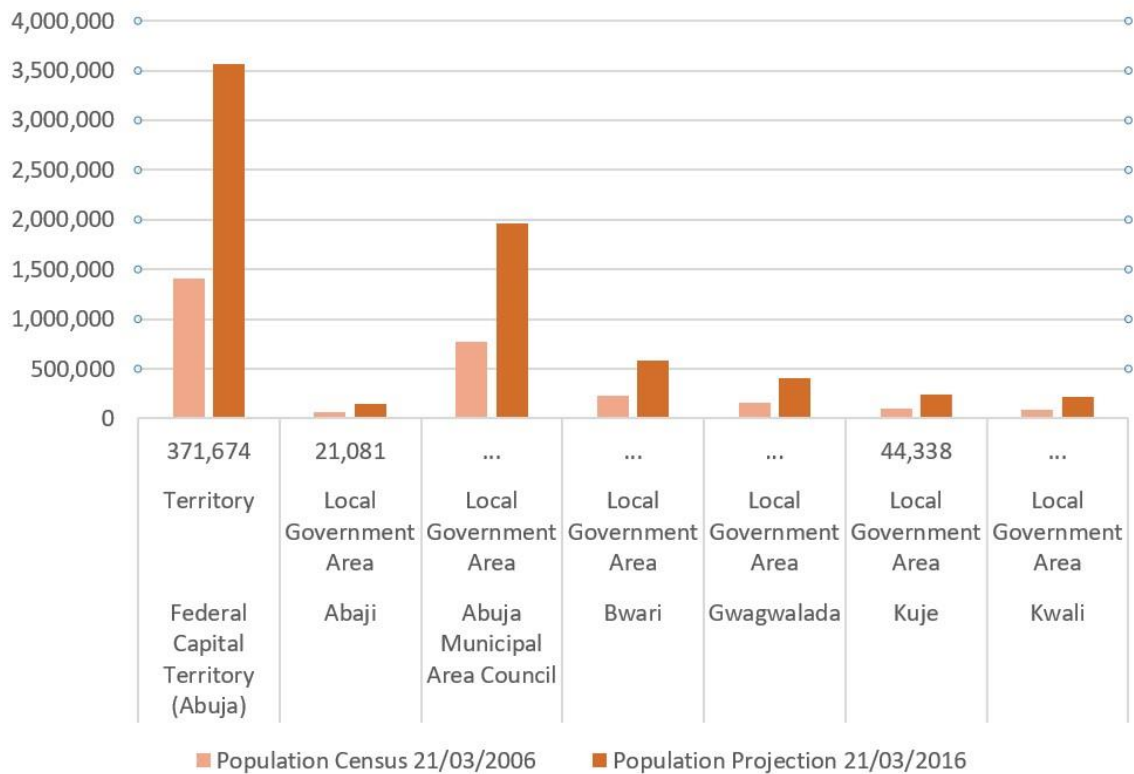


Figure 5: Population distribution of FCT. (City population.de, 2020)

Figure 5 shows the population distribution of the six area councils. The Abuja Municipal Area Council (AMAC) has the highest demographic number out of all the areas.

A study was conducted by the Women Environmental Programme (WEP) in collaboration with the National Bureau of Statistics (NBS), with the support of Open Knowledge International (OKI), under the African Open Data Collaboration Fund. Within this study, a survey was conducted in three (3) Area Councils of the Federal Capital Territory, Abuja - AMAC, Gwagwalada, and Kuje Area Councils regarding the basic amenities in the area. According to this study, 36.83% of communities in AMAC are not connected to the national grid, 72.76% are not served by public water supply, 57.89% have no primary health care facilities, and 74.92% have no waste management systems.

These figures are exacerbated by IDP camps' presence in these areas generally as they become settlers within host communities, thus reducing the availability of amenities in the area.

2.3 Climate

2.3.1 General climate data

Under the Köppen climate classification, Abuja has a tropical wet and dry climate (Köppen: Aw). Annually, Abuja experiences three different weather conditions. This comprises an intense dry season, a humid and warm rainy season, and a brief Harmattan interlude. The northeast trade wind usually accompanies the Harmattan, bringing

a lot of dryness, haze, and dust. Abuja lies at 477m above sea level. FCT is located in the zone of the rising air masses because it is on the windward area of the Jos Plateau. This means it is more prone to rainfall, especially during the rainy season of April to October yearly. The average annual temperature in Abuja is 25.7 °C | 78.3 °F. About 1389 mm | 54.7 inch of precipitation falls every year (ClimateData.org, 2020).

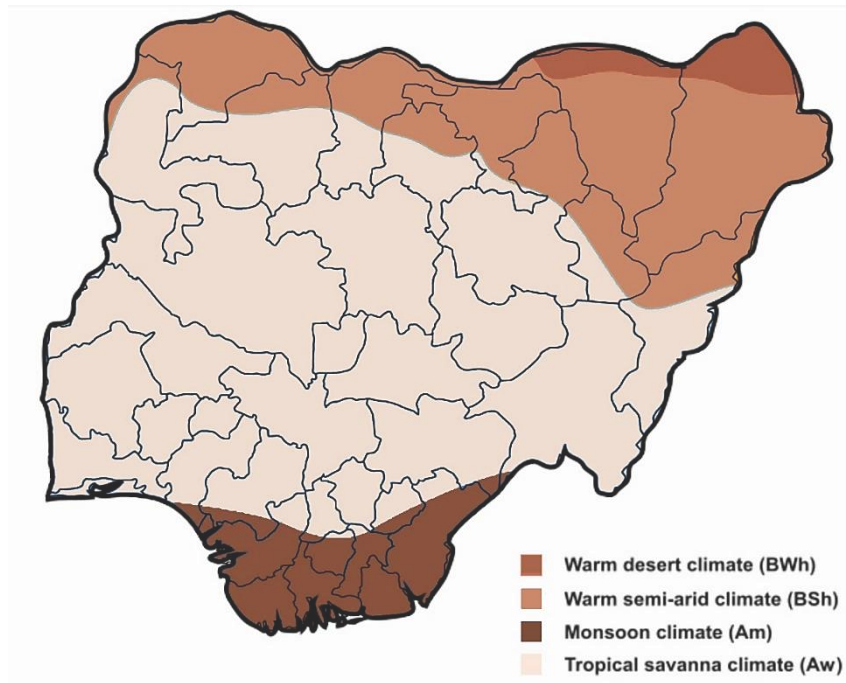
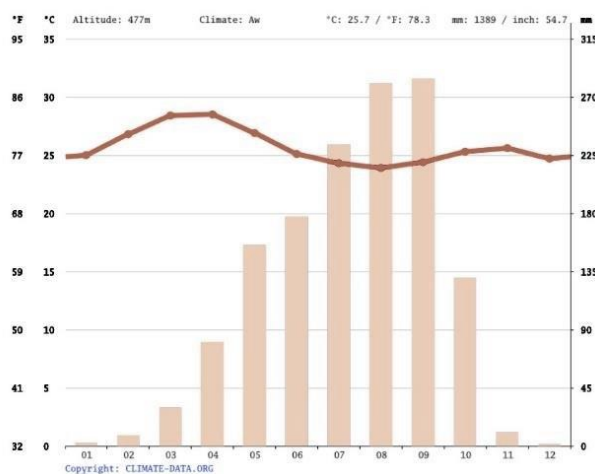


Figure 6: Nigerian map of Köppen climate classification (https://en.wikipedia.org/wiki/Climate_change_in_Nigeria#/media/File:Nigeria_map_of_K%C3%B6ppen_climate_classification.SVG)

ABUJA CLIMATE GRAPH // WEATHER BY MONTH



ABUJA AVERAGE TEMPERATURE

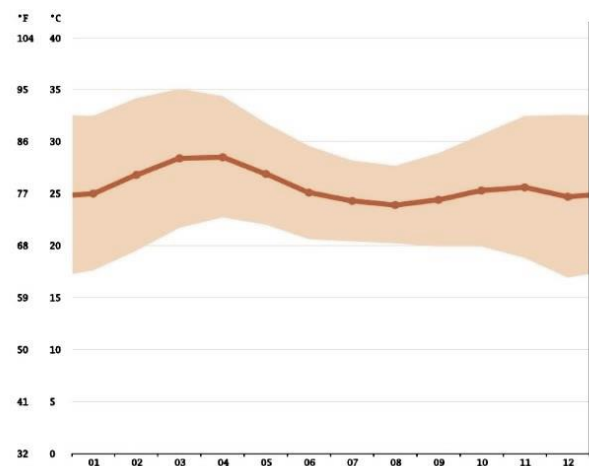


Figure 7: Abuja climate graph and average temperature. (Climate-Data.org, 2020).

December is the driest with 1 mm | 0.0 inch of rain. September has the highest amount of precipitation, averaging 284 mm | 11.2 inches. August is the coldest month, with an average temperature of 23.9 °C | 75.0

°F. The temperature in April averages 28.5 °C | 83.3 °F. The wind rose for Abuja shows that the strongest prevailing winds are the South Southern and southwest winds, and they are strongest in April.

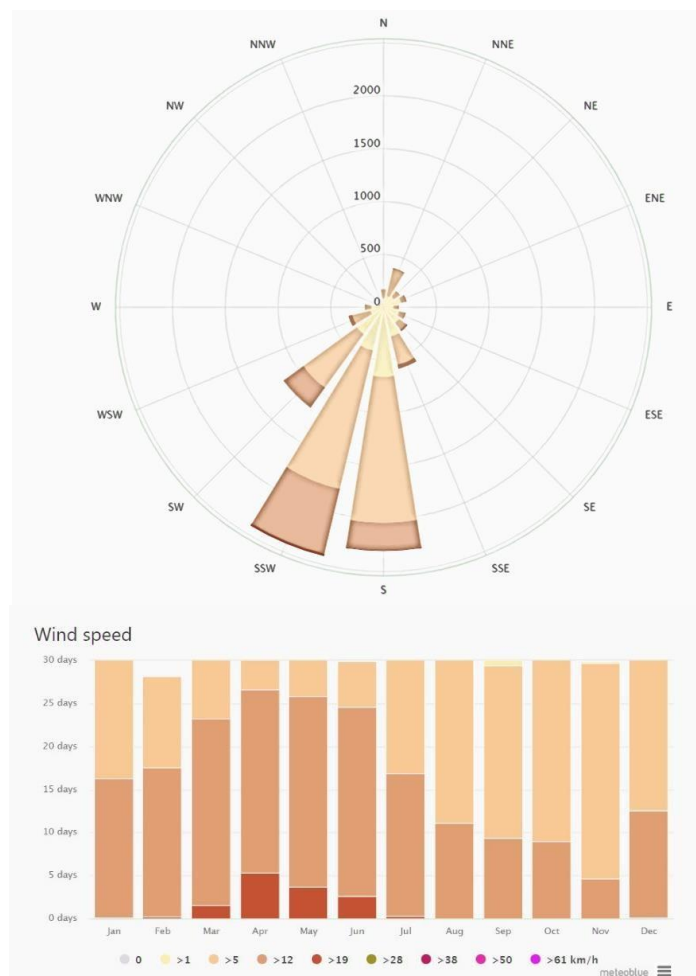


Figure 8: Abuja average wind direction and wind speed. (Meteoblue weather, 2021).

2.32 Climate threats

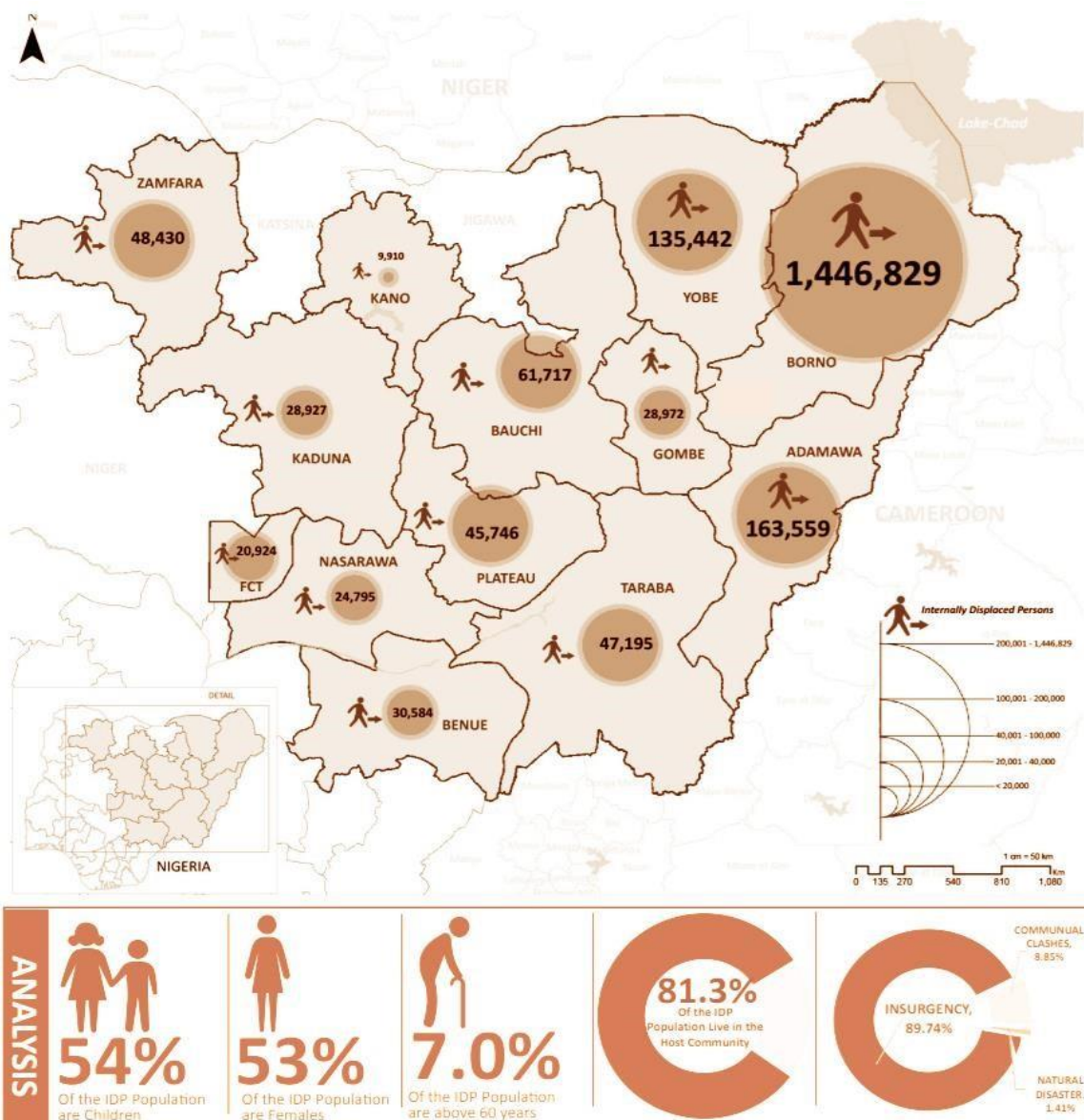
Over the next hundred years, there will be a significant level of climate change. This phenomenon will impact the design of buildings and the built environment at large. Nigeria's climate has been gradually transforming, evident in sea-level rise, flooding, desertification, drought, land degradation and increased extreme weather events. There is a lot of variation in the rainfall as the intensities and duration have increased. On the other hand, droughts have also become frequent and are expected to increase in Northern Nigeria, where Abuja is situated. Climate change throughout Nigeria is discussed in a few comprehensive reports but mainly regarding the agricultural sector. Some comprehensive papers and reports provide helpful proof and discuss the numerous effects of climate change in Nigeria. Most of the information that gives proof of climate change, responses and impacts focus on individual farming communities and the agricultural sector in particular regions of the country. According to research (Haider, 2019), the literature typically gives recommendations as adaptation and mitigation methods instead of already implemented strategies. Some ways to help alleviate the impacts of climate change in Nigeria are to strengthen climate change knowledge architecture and integrate sustainability into rural environments and educational curriculums. This sensitisation will enlighten the general public to reach community-based organisations, researchers, policymakers, and students who are in the front line of delivering adaptation projects (Amanchukwu et al., 2015). In an ideal world, architecture needs to reflect

reality; enlightening the public while designing buildings allows for considering real-life issues while creating the built environment. In summary, we need to reduce greenhouse gases in the atmosphere while simultaneously managing the irreversible effects of climate change.

2.4 IDP Camps

2.41 Introduction

One of the leading roles in Nigeria's recent history is the Boko Haram insurgency. After the Nigerian Civil war of 1967-1970, this has been the leading cause of displacement (Olanrewaju. F et al., 2019). The Boko Haram insurgency started in 2002; however, it was exacerbated by the assassination of the leader Mohammed Yusuf while in police custody. The surviving sect members fled into bordering African countries through the permeable Nigerian borders where they could receive training in creating IED's (improvised explosive devices), connections with mercenaries and funding. Thus, the Boko Haram sect became recognised by using extreme violence to instil fear into the general Nigerian population, especially in Northeast Nigeria. The conflict led to the displacement of about 3.3 million people (Olanrewaju. F et al., 2019). The North-Eastern states of Borno, Yobe and Adamawa experienced the most displacement of people. The neighbouring Northern states experienced an influx of people from these regions, as shown in the diagram below.



Caux (2013) makes the distinction that people fleeing to other countries for refuge are referred to as refugees while the people who escape to locations within the country are labelled IDPs. According to the Kampala Convention of 1969, also known as the Organization of African Unity Convention, Refugees are persons who owing to external aggression, occupation, foreign domination or events, seriously disturbing public order in either part or the whole of his country of origin or nationality, is compelled to leave his place of habitual residence in order to seek refuge in another place outside his country of origin or nationality.

However, the 1998 Guiding Principles on Internal Displacement defined IDPs as persons or groups of persons who have been forced, obliged to flee, to leave their homes or places of habitual residence; in particular, as a result of or in order to avoid the effects of armed conflict situations of generalised violence, violations of human rights or natural or human-made disasters, and who have not crossed an internationally recognised state border. (United Nations Office for the Coordination of Humanitarian Affairs [UN OCHA], 2004).

These definitions show similarities between refugees and IDPs, such as causes and shelter needs. However, the main distinction between the two groups of persons is whether an international border is crossed or not. This distinction is important because it reflects how the government treats each group differently with regards to housing. The differential treatment between the IDPs and refugees will be elaborated upon in a subsequent chapter.

The Federal Capital Territory of Nigeria is one of the locations in which the IDPs take up residence. Although Abuja is one of the less populated IDP regions of the country, it is continuously increasing every year as the conflict in the North East is still ongoing. IDPs destination is mostly to three major places within the cities,

- Host communities
- Official IDP camps
- Safer Neighbouring countries outside the country of displacement

The Federal capital territory has 21 officially recognised IDP camp, as outlined in table 2 below (Edem-Nse. Y. G, Muhammad. I. B & Momoh. S. A., 2017).

S/N	I.D.P Camp location	Location	Population
1	Abuja IDP Camp	Gidadaya, Orozo	754
2	Unamed	Kagruma, Kwali	204
3	Gwoza and Bama IDP Camp	Durumi II, Area 1	2226
4	Internally Displaced Persons Camp, New Kuchingoro	New Kuchingoro	782
5	Internally Displaced Persons Camp, New Kuchingoro	New Kuchingoro	500
6	Karmajiji IDP Camp	Karmajiji, City Gate	340
7	Building Market Camp	Saburi II, Dei-Dei	710
8	Guzape Internally Displaced Persons Camp	Guzape, Asokoro Extension	661
9	Internally Displaced Persons Camp	One Man Village	720
10	FCT III, Internally Displaced Persons Camp	Kutunku II, Gwagwalada	711
11	EFAB IDP Camp	Apo Mechanic Village	426
12	Abuja Internally Displaced Persons Camp	Durumi I, Area 1	671
13	MSSN Camp for the Internally Displaced	Lugbe I, Airport Road	543
14	No Name	Waru, Gwagwalaga	1023
15	FCT II Internally Displaced Persons Camp	Kwali	502
16	No Name	Kuje	763
17	No Name	Wassa	997
18	Kutunku Internally Displaced Persons Camp	Old Kutunku, Gwagwalada	210
19	Unnamed	Piwoyi, Lugbe	678
20	FCT I Internally Displaced Persons Camp	Kuchiyako	987
21	NASFAT Internally Displaced Persons Camp	Back of Market, Karmo	432

Table 2: IDP camps in FCT Abuja (Edem-Nse. Y. G, Muhammad. I. B & Momoh. SA, 2017).

2.42 Official housing policies for IDPs within Abuja

The delivery of essential services is the government's responsibility. Still, it might be supported in the short and medium-term by humanitarian and development actors when capacities are insufficient and the focus on the areas of displacement and return. According to the National Nigeria policy, chapter 3, subsection 3.13

"All IDPs shall have the right to an adequate standard of living. At the minimum and without discrimination, relevant authorities shall provide IDPs with safe access to essential food and water, basic shelter and housing, appropriate clothing, and essential medical services and sanitation. Women should be full participants in the distribution of these supplies. Good conditions of safety, nutrition, health, and hygiene should be ensured." National Legislative Bodies / National Authorities (2012).

The National Emergency Management Agency (NEMA) is the foremost organisation responsible for the IDPs residing within Nigeria (Levinus, 2015). There are various branches in all the states, referred to as State Emergency Management Agency (SEMA). The main headquarters is located in the Federal Capital Territory, Abuja. According to Akujobi of the NEMA Headquarters in Abuja, *"NEMA works hard to attain the highest ethical international Standards supported by their international partners."* (Amina, B. Z. J., & Ibrahim, S. G., 2019). However, according to the Zonal Coordinator for NEMA, the IDP settlements are informal and should be classified as "locations" Abbas (2016). They cannot be referred to as camps because they do not comply with the UNHCR requirements. Therefore, there is no official housing policy for them.

S/No	Description	Minimum standard
1	Covered living area	3.5sqm per person Minimum ceiling height of 2m
2	Camp settlement size	45sqm per person
3	Fire safety	Minimum of 2m between structures or two times the height of the structure
4	Gradient of campsite	1 to 5%
5	Drainage	Appropriate drainage must be put in place, especially in locations that experience drainage difficulties in rainy seasons.













Table 3: UNHCR 2015 Checklist for Assessing IDP Camps (UNHCR, 2015).

The decision of the government to not acknowledge the IDP camps results in the lack of official funding. According to Abbas, the zonal financing of the "unofficial camps" are unplanned. He states that the Federal Government does their best to provide funding; however, they mostly rely on private individuals, governmental agencies, local and international organisations. Many IDPs are in Abuja are in host communities, and their actual numbers are unknown.

2.43 Economics

The purchasing power of the Naira must be understood to contextualise the economics within the IDP camp. In order to gain a better understanding of purchasing power, specific comparisons are drawn according to living cost.org, as shown in the image below.

Prices in the Netherlands vs Nigeria - Cost of Living Comparison

	Cost of living One person	€1382	€666
	Cost of living Family	€3292	€1702
	One person rent	€796	€383
	Family rent	€1298	€898
	Food Expenses	€371	€173
	Fast food meal, equiv, McDonald's	€7.45	€3.92
	Monthly salary after tax	€2262	€143
	Apartment price in city centre 1m2 or 10ft2	€3649	€436
	House price to buy in Suburbs. 1m2 or 10ft2	€2716	€184
	Local transport ticket	€2.87	€0.35
	Gas/Petrol	€1.52	€0.31
	GDP per capita	€43754	€1674

Salary adjustment calculator

The estimated difference in money purchasing power



€1000
Netherlands



€482
Nigeria

Figure 10: Cost of living comparison between the Netherlands and Nigeria. (Livingcost.org, 2020).

The purchasing power of Nigeria is less than half of the Netherlands. This means that the same amount of money in the Netherlands can acquire about twice as many products in Nigeria. As a result, the average cost of living in the Netherlands (€1394) is 107% more expensive than in Nigeria (€672). The Netherlands ranked 16th vs 92nd for Nigeria in the list of the most expensive countries in the world. The average after-tax salary is enough to cover living expenses for 1.6 months in the Netherlands compared to 0.2 months in Nigeria (livingcost.org, 2020).

The majority of IDPs within Abuja originally had the occupation of farmers. However, due to displacement, they are extending their stay indefinitely within the city. The circumstance detaches them from their safety networks, original agricultural source of income, and substantial underdevelopment of skills needed to regain their livelihood in a less agricultural, urban environment. According to a study (Ishaku, J. et al., 2020), the patterns of displacements are changing from routine mass movements during the initial start of the conflict in the mid-2010s to prolonged settlement in the camps. The majority of residents in the study have been in the camps for four to six years, with the average household comprises four to seven members, as shown in figure 10. This data indicates that although these living situations are supposed to be temporary, the expectation of permanence is gradually increasing.

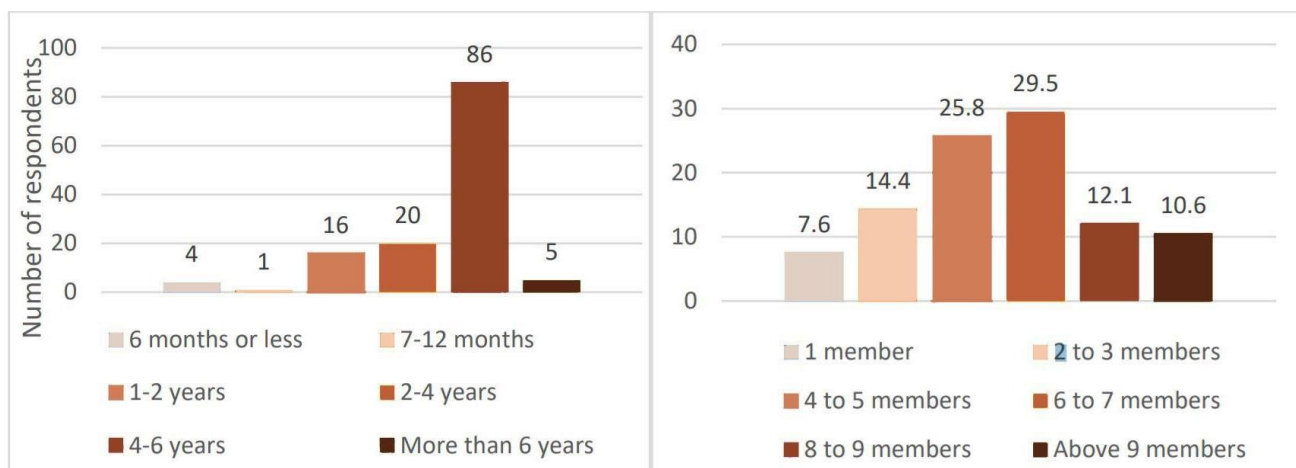


Figure 11: Distribution of duration of stay and Household size (per cent) location. (Ishaku, J. et al. 2020).

According to the study, about 72.5% of respondents have a primary education; this shows that the education received in their states of origin did not equip them with adequate skills required for formal economic jobs. Moreover, formal education is not taken very seriously because the rural regions focus on an agricultural way of life and more informal engagement. Nevertheless, over the past few years, about 50% of the residents of these camps have been provided with apprenticeship opportunities, basic skills and training in areas such as welding, welding, tailoring and many other blue-collar jobs.

Poverty is a concerning issue among IDPs in the surveyed locations. About four-fifths of the respondents surveyed earn less than NGN (Nigerian Naira) 20,000 monthly. For context, this translates to living on less than EUR 1.58 daily. Additionally, 71% of respondents reported earning less than NGN 10,000 per month (EUR 21.87). In 2019, the official national minimum wage of NGN 30 000 (EUR 65.61) became law (Varrella, S., 2020). Since most households consist of at least four people, the wage of IDP camp residents is low; therefore, they can be classified as low-income earners. It is also important to note that about 54% of respondents confirmed that donations in cash or kind supplement their monthly incomes. Although the lower-income earners do not have much access to these donations, there is room for improvement in order to ensure the donations are distributed to the persons who require them the most.

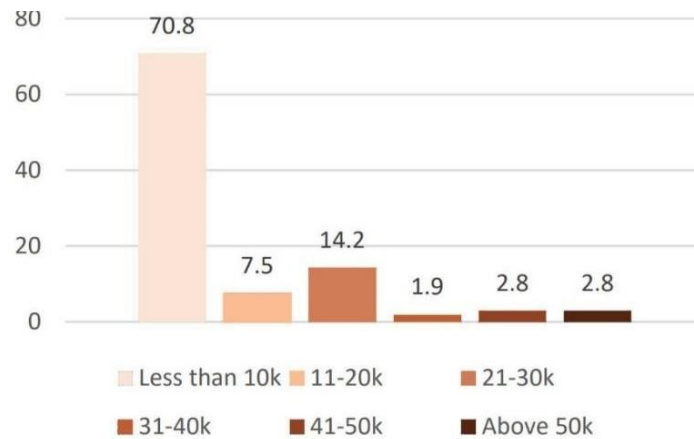


Figure 12: Distribution of average monthly income (Ishaku, J. et al. 2020).

2.5 Conclusions

After looking at recent Nigerian history, it was imperative to understand the regional context, demographic distribution and main issues concerning the development of IDP camps.

The findings show that most IDP camps within Abuja are host communities helping those fleeing from the war in the northeast. These regions are economically poor; however, there is an opportunity for development within them, such as

- Collaboration with organisations to provide a sustainable housing typology.
- Re-use and recycling of materials
- Create opportunity for IDP and host communities to come together and grow economically.

The main issue now is how the literature research conducted in this chapter will inform the design brief for the building component in the IDP camps.

- Passive climate design principles

The local climate is tropical; thus, it is very suitable for implementing passive design strategies. The exact principles to be utilised will be elaborated upon in the subsequent chapter.

- Nature of building component.

Although the IDP camps should serve as temporary living situations, the degree of permanence is increasing every day. Thus, the construction elements should be sturdy enough to be used for an extended period, however, they should be easily demountable.

- Local economy stimulant

The production of the building component should be as low cost and easy as possible. The system should also enhance the local economy by providing skills, local labour, and housing for the communities. In doing so, members of these communities would have increased job opportunities while also being educated about climate change and sustainability.

3

The people living in IDP
camps (Kuchingoro as a
case study)

AFRICA



NIGERIA



ABUJA



KAURA



KUCHINGORO IDP CAMP



3.1 Introduction

In designing a building component, it is imperative that right from the beginning of the design process, the end-user should serve as the focus of the end product. Therefore, an informal site visit comprised of interviews and analysis of the IDP camp is conducted as part of the research. The purpose of face-to-face interviews and on-site study is to verify some answers found in literature and uncover answers that will assist in forming the design brief.

How did people come to live in Kuchingoro IDP camps, and what are their occupations or day-to-day activities?

The persons residing within the camp determine what the local context will be. How do they earn a living, and how does this vary from household to household? What are their daily routines or lifestyle on a day-to-day basis? The overall quality of the building design is improved when these housing-related aspects are understood.

What are the desires and needs of people living in IDP camps?

Human beings have wants outside of the basic needs of clothing, food and shelter. This helps determine their housing-related desires and how the development of a building component can help fulfil that desire.

What is the role of community participation in developing a building component?

The building component should add benefit to the community as a whole. People need to be involved in the process actively at all stages to ensure it's a success. Is it possible to integrate the building component into their existing surroundings? A basic understanding of the different people will give an idea of whether or not this is possible.

3.2 Kuchingoro IDP camp

The building component is to be designed for a low-tech application in an IDP camp; therefore, the first point of reference should be an IDP camp within Abuja. **The Kuchingoro IDP camp is located within the Kaura district of Abuja, and it is one of the larger camp settlements within the city.** It is an informal camp-like site almost wholly made up of temporary, scrapped together shelters inhabited by locals and IDPs from the North Central and North East states such as Yobe, Kaduna Bauchi, Nasarawa, Jos and Borno.

The first set of IDPs relocated here in 2014; they have built settlements extensively on the piece of unused land in Kuchingoro. The camp is purpose-built and is still evolving as new IDPs are still migrating there. According to FEMA, it is one of the "unauthorised" camps (Aloba, Adebawale, 2020). This means that they are unregistered according to the agency responsible for their care and management. This label prohibits the possibility of them receiving any aid. They once received help from FEMA in the early stages of establishment; however, this aid has stopped, and the people in this camp now depend on NGO's, good Samaritans and religious institutions. The piece of land was left unclaimed, and this makes the residents fearful of eviction. Kuchingoro is rapidly evolving into a suburb within Abuja, with new buildings erected on surrounding lands.



Figure 13: Bird's eye view of Kuchingoro IDP camp. (Aloba, Adebawale 2020).'

3.3 The People of Kuchingoro IDP camp, person to person interview

As part of the literature research, stories about the lives of different individuals living in the New Kuchingoro IDP camp are gathered through interviews. During on-site analysis, there was an opportunity to meet various residents of the IDP camp in person. The descriptions below are my personal experience during site visits in February 2021.

To follow proper protocol, ensure that we were in compliance with the rules of the camps and ensure safety, the camp secretary, Mr Yathuma Luka, was contacted to facilitate interviews with some of the residents. Due to the Covid-19 pandemic, only four different people are interviewed. Each was selected because they represent a different household, thus offering a different perspective.

Before interviewing the residents, I had a conversation with Mr Luka, who revealed that he was among the first set of IDPs to relocate to the New Kuchingoro camp in 2014. He became the secretary due to the leadership nature which he exhibited, and now he is the spokesperson for the entire camp. It is not an official role, but it is essential because it helps keep things in order. He explained that the IDPs tend to hold allegiances based on state lines, creating a tense environment within the camp. Every state or community prefers to have a spokesperson; therefore, the hierarchy of the camp is such that there is a Chairman, Vice Chairman, Women's Leader, Secretary, and eight different Community leaders. This power allocation ensures that relief materials donated to the camp are shared based on immediate need, and every community receives a fair share. The system has led to things moving more smoothly within the camp; it has also substantially de-escalated hostilities between the different communities. One thousand seven hundred twenty-four registered people live in the camp as of the time of the interview (February 2021). The interview takes place in the local Hausa language; translations are as accurate as possible.

Mr Luka introduced four residents, namely.

Elizabeth Pilimo - Petty trader

Naomi Yohanna – Petty trader/farmer

John Nuhu - Unemployed

Yohanna Ishaku - Carpenter/ Generator repairman

3.31 Stories and interviews

i. Elizabeth Pilimo

She is an indigene of Goshe village in Gwoza local government, Borno state, located in the North-Eastern part of Nigeria. She is a petty trader who sells local food such as masa, groundnut, and ridi for a living. She is married with six children. Her husband is a farmer in Nasarawa, a neighbouring state, who travels periodically every two weeks to go and farm or make the harvest. Her family arrived at the camp in 2014 and intended to reside in the camp temporarily until the end of the civil unrest in their hometown; however, that is yet to happen. She earns about NGN 15,000 (EUR 32.60) a month, and her husband makes between NGN 8000-10000 (EUR 17.39 – 21.73) depending on the farm harvest.

Her favourite aspect of the camp is the community bonding and spirit between her and her fellow women. They cook together, clean, learn trades and support each other as best as they can. Cooking areas are generally

located close to their housing. These serve as an area for communal activities, mainly between the women. When asked about fire concerns, especially with their housing made of all flammable materials such as plastic and wood, she said that cooking outside is something they have done all their lives, so they know how to make it work. Some kitchens are located close to the living areas; however, these areas have wooden panels and some space for air to pass through.

Her primary concern in the camp is for her children's safety and wellbeing. Young kids are exposed to young men who make a local brew that is intoxicating. Many of the youth within the camp are addicted to the drink and other drugs. According to Elizabeth, it presents many safety concerns for her and her family.

For housing, they live in a shack which she refers to as a 'bacha'. Her family resides in two of these. One bacha for Elizabeth, her husband and their youngest child, while the other bacha is for the rest of the five children. They usually source wood from the camp itself as trees and construction sites are abundant all around, and they hired a carpenter to put the bacha together. It took them about a month to gather all the materials necessary but just one day to build each bacha. In this way, the incremental building is valued in the camp.



Figure 14: A- Central road in Kuchingoro IDP camp

B- Elizabeth Pilimo in front of her bacha

Another concern she stated is the lack of efficient housing structures, Elizabeth explains,

"Other camps that are recognised are built with concrete, and ours are these structures that are not stiff enough to prevent water from gathering and pouring into our room when we are sleeping".

The tarpaulin material is not stiff, wood and zinc would be the preferred option, but it is just not possible due to their income. They can only afford wood for the frame of the building. She says zinc is classified as the most high-class material, which is surprising because metals are excellent heat conductors, making it uncomfortable if applied as a building material without insulation.

She said, *"you can always cool a place down, but you can't run away from water".*

She ended her interview by saying that she would like to increase her earnings and would appreciate it if her husband did not have to travel to the farm so often.

ii. Naomi Yohanna – Petty trader/farmer

Naomi Yohanna is originally from Gboko village in Borno state. She has two children, but unfortunately, her husband passed away from illness, so she is left to fend for her family independently. She works two jobs, one of them is selling drinks and sweets, and the other is she goes to the farm periodically. She earns anywhere from NGN 20,000 (EUR 43.47) to NGN 50,000 (EUR 108.67) monthly

With regards to housing, she has one bacha in which she and her two daughters reside. She also complained quite bitterly about how many of their materials have been ruined by water because the wrapping used as the façade covering is not strong enough to hold the water. Furthermore, it is so thin that sometimes rodents easily chew through the tarpaulin, leaving them exposed to the elements.

She bought an already existing bacha when she came to the camp in 2014, and she changes the plastic sheeting about once a year if she can afford it. The bacha sheets are sold at around NGN 4000 (EUR 8.69), NGN7000 (EUR 15.21) or NGN 8000 (EUR17.39) each for the large coverings or NGN 100 (EURO.22) each for the smaller cement bag sheets. When asked about the plastics' end of life, she says,

"We try not to throw them away; we re-use them on the ground to prevent water from flowing into the rooms".

She also does not do any maintenance work herself; she always calls a carpenter to replace things or fix any problem. The floor is usually bare, with just a carpet laid over it. If one has extra money, the carpenter can cast a concrete base. While at her bacha, it is noticeable that there are no window openings; when asked about that, she reiterated water problems. There is a semblance of an opening in the small kitchen beside the bacha, as shown in the figures below.

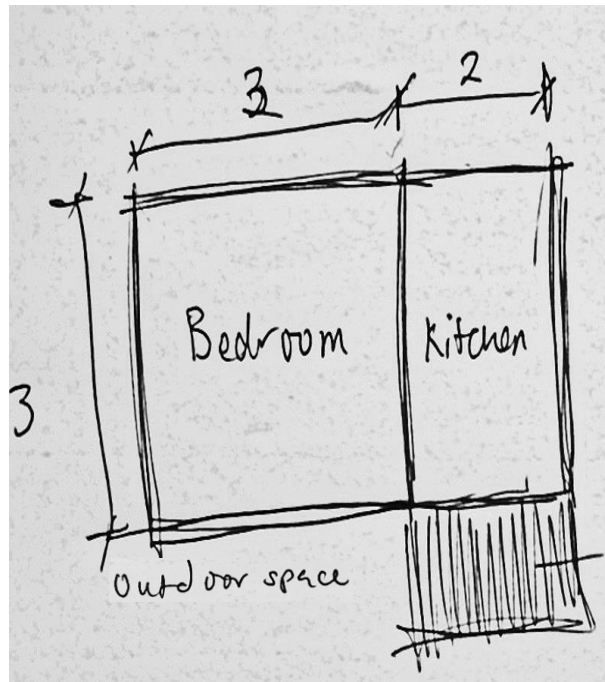


Figure 15: Schematic view of Naomi Yohanna's bacha with an adjoining kitchen.

She shares the same concern with Elizabeth regarding the problem of alcoholism and vices and their influence over the children. She would also like to continue with her trading job, but the farming job can be very tasking,

and it takes her away from her children. She mentioned that different organisations have set up skill acquisition programs, and a lot of the women in the camp have taken up sewing as a trade now. She is open to the idea of taking up a trade that would allow her to stay at home longer. Sometimes good Samaritans come to the camp to teach women skills such as sewing, braiding and weaving, which helps them become self-subsistent for their families.

iii. John Nuhu

He is also from Gwoza local government in Borno. He used to live in Kabusa, another area in Abuja. However, he had an accident and could not provide for his family anymore; therefore, he moved to the camp in 2016. He has one wife and five children. His wife took up his previous farming job, but now she is a cleaner who earns between NGN 16,000 (EUR 34.77) to NGN 20,000 (EUR 43.47) naira per month.

He is generally out of work because his accident left him unable to move or stand for too long. He would desperately like to get a job to support his wife and cater to his children like he used to. His day-to-day activities consist of staying in the camp, seeing his children off to school, going to the nearby church and spending time with others who may also be unemployed within the camp.

With regards to housing, they moved into one bacha, and when they had enough money, they were able to build one more for the children.

He stated that *"if you can develop a better building material for us, we don't mind if it is a bit more expensive; it just needs to be better"*.

When asked about general safety in the camp, he said people generally don't break into people's home to steal. Belongings are only unsafe when left outside. *"Most of our bacha's don't even have windows, there's only one way in or out, and everyone knows where everyone lives. It's not so easy to steal."*

iv. Yohanna Ishaku

Yohanna is the resident head carpenter within the camp. He is also from Borno, Gwoza local government, and he moved to the camp in late 2013. Apart from carpentry, he also repairs generators and provides maintenance for all the bachas in the camp. He has facilitated the creation of jobs because he trains young men in the craft. They end up working for him, and he provides payment of NGN 2000 (EUR 4.34)- NGN 5000 (EUR 10.87) per person. The total cost of building a bacha, according to him, is about NGN 20,000 (EUR 43.47). Once he builds it and pays his workers, he ends up receiving about NGN 1500 (EUR 3.26)- NGN 2000 (EUR 4.34) as profit for himself.

His own home in the camp is one of the biggest; he has maintained it for the past six years because he has the expertise to do so. He also earns the most income of all the interviewees, NGN 30,000 (EUR 65.20) to NGN50,000 (EUR 108.67) a month. However, he has one wife and seven children to take care of, so he will not move out anytime soon. Yohanna provided information on exactly how these shacks are built and the cost breakdown. This local building technology will be explored in the next chapter.

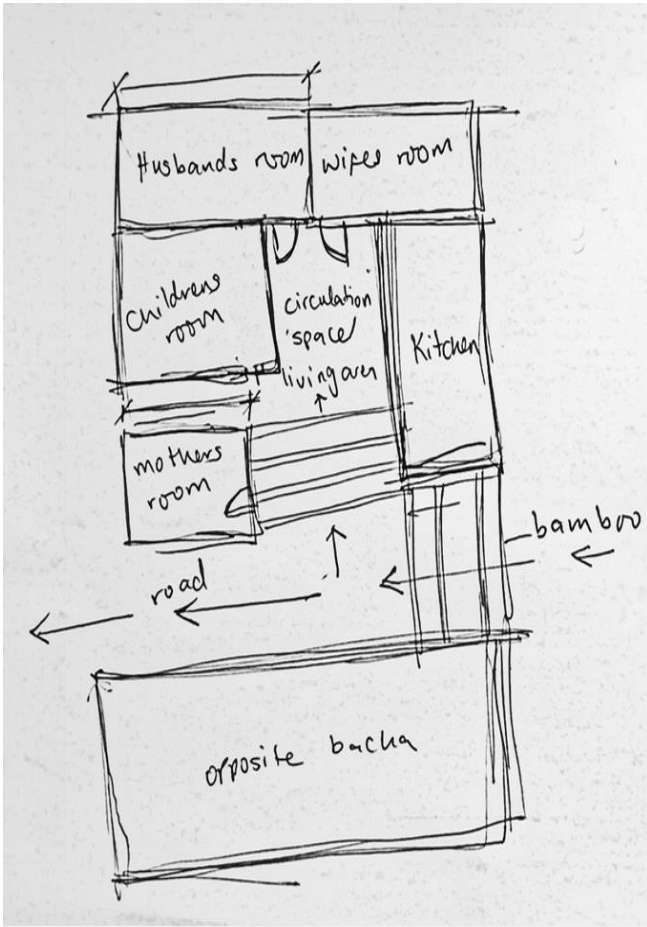


Figure 16: A- Plan view sketch of Yohanna's bacha.



B- Entrance of Yohanna's bacha



Figure 17: Yohanna standing in front of his bacha.

3.32 Lesson from interviews

The people interviewed showed various concerns of people who live in Kuchingoro. There are many problems they face daily, but the interview is geared at understanding their daily lives, especially with regards to housing. This understanding determines what similarities in their stories can result in requirements for the design brief of the building component. All the residents confirmed that there is some tension within the residents from different states, especially with the distribution of relief materials. Still, over time this is reduced considerably because of the systems put in place in the camp. People seem to cook outside their houses. Even if the kitchen is close to the housing, it's never inside the house. The building component should be able to be as safe as possible, but it is not the most pressing concern as they are used to it already. They all understand the need to re-use plastic as they use plastic bottles to store drinks and re-use the plastic tarpaulin until it cannot be used anymore.

All the houses visited has little to no daylight due to the lack of windows. There are hardly any windows. If any, it is located close to the top for safety purposes as well as privacy. Lighting within the housing is through the use of kerosene lanterns or electricity from wires attached to bamboo poles on the shacks. However, the lack of lighting does not seem to bother them much because their communal activities are mostly outside. They only go to their bachas to sleep or use it to store their belongings; if there is a kitchen, they also cook.

One other recurring similarity in the interviews is that every bacha is meant to house one segment of the family, either the parents or the children. These are usually separate, but the bachas can also be joined if it is a larger family space. Sometimes the residents can buy bachas from their neighbours and expand their homes.

The most important aspect to note is that all four of them concurred that zinc is the most valuable material to them in terms of housing. It is stiffer and more resistant to water leakage than the plastic tarpaulin or cement bags they use now. Wood is the second most preferred material. All of them agreed that a change from the tarpaulin would be best; however, their actual rooms are okay for the present time.

4

Local Building Technology



4.1 Introduction

The main focus of the design brief will be on the technical aspect, even though the complete design for reasonably priced building components is an integrated task. This chapter explores the creation of a technical framework by providing answers to specific questions.

What are the existing building methods in IDP camps?

An important starting point is to determine the current methodology of building construction within these camps. This gives an understanding of what the local community is familiar with to make sure the design brief is as relatable as possible. What are the different building methods used within this camp, and what are the immediate problems with their housing?

There are different building methods within the camp; however, the most important for the design brief are the houses in which people actually reside. Therefore, the qualities of the housing units in the camp should be analysed, how functional they are, and how they impact those who live in them.

What are the locally available products and resources?

This paragraph will give an overview of available materials and methods to define the design brief's scope. It also assesses the production techniques and materials applied within a local scale.

What are the other low-cost housing options available?

This paragraph will explore the traditional construction methods of the people present in the camp will be explored. It is essential to take the original local architecture of the people into consideration in the design brief.

What are efficient methodologies for smart climate design in low-cost housing?

Nigeria is a tropical region that is also experiencing increasing temperatures due to climate change. The building design should take into account the indoor comfort of the residents. Thus, a fundamental knowledge of basic climatic principles is vital in order to design a building component.

4.2 Existing building methods

4.2.1 Building methods in IDP camps

The IDP camps employ building methods that are dependent on the availability of raw materials. These are often inventive as they have to re-use waste materials. These techniques are somewhat repetitive throughout. The analysis for this building methods is based on previous studies and site visits. Generally, the shelters are made up of a wooden frame constructed from raw wood or sawn wood. They usually employ the skills of a local carpenter to build the wooden framework and then place the water and windproofing cladding materials themselves. Sometimes the structures are made out of concrete or metal, which can be load-bearing materials.

These are usually not the norm and are often made by donations or by the government themselves, as residents cannot afford to do so themselves.

i. IDP Camp, New Kuchingoro, Kaura Abuja

There are different methods of construction within the New Kuchingoro IDP camp. The most prevalent form of construction is the bacha which serves as accommodation for most of the residents. The bacha is a traditional name for a shack. A typical shack structure is made up of a structural framework constructed from sawn wood or raw logs. This framework is usually put together with the use of aluminium nails. In order to protect the accommodation from the elements, different cladding elements are used. The most popular one being tarpaulin bags made from polypropylene.



Figure 18: A- Raw logs wooden framework.



B- Sawn logs wooden framework

The more important buildings such as the school, chicken coop area and communal hall are built using zinc-coated sheets or wooden panels as cladding. These are the more expensive materials; thus, the residents primarily live in bacha's made from wooden structures and polypropylene sheets. The load-bearing walls made out of containers or cement bricks are not so common within the camp. None of the residential buildings is constructed with load-bearing walls.



Figure 19: Communal and storage space made out of wood planks and zinc-coated roofing sheets.



Figure 20: Communal hall made from a combination of wood, roofing sheets and a load-bearing wall.



Figure 22: Skill acquisition centre made of containers donated by charities. (Google maps. <https://www.google.com/maps/place/IDP+CAMP/@9.0087584,7.435085,17z/data=!3m1!4b1!4m5!3m4!1s0x104e7310f18b966d:0x32db60edc7c0c551!8m2!3d9.0087584!4d7.4372737>)



Figure 21: The women's leader Ladi Mathias standing in front of the toilets. (Tong, T., 2017).

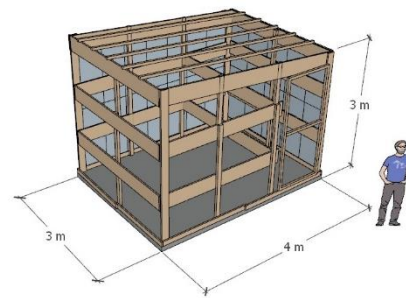
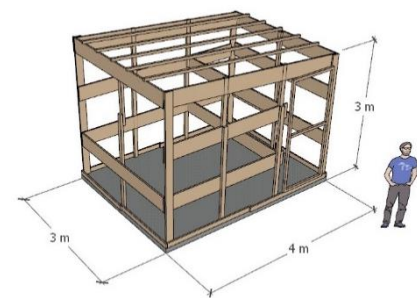
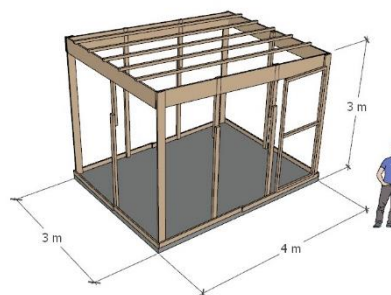
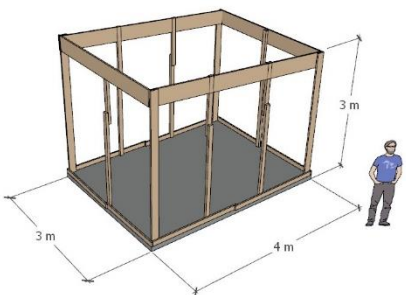
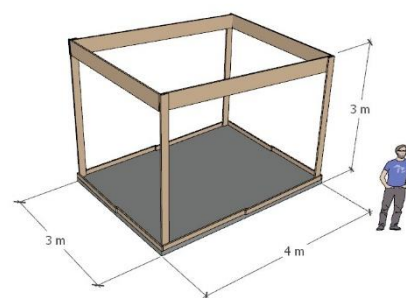
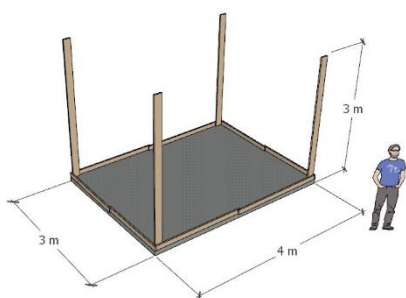
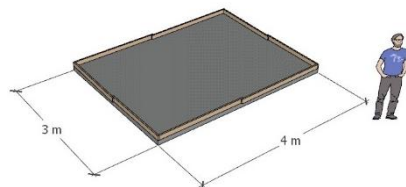
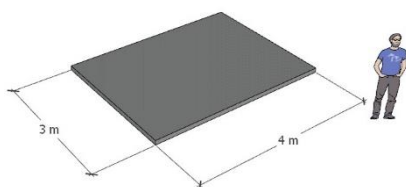


Figure 23: Doors in the camp made from Wooden frames, chicken wire, zinc-coated sheets and wooden planks.

During the site visit, Yohanna explained the process of building the accommodation shack in the camps, the cost of doing so and the end of life of the materials. Some residents gather the materials bit by bit until they have enough to build an entire bacha, while others give him the money directly to do so. Building materials are recycled or unused materials from building sites or within the camp itself, as the camp is situated on a piece of land with many trees. He also confirmed that most people use polypropylene cement bags due to economic reasons, but zinc coated sheets are the most sought-after material. About 15-20 wooden planks are used. They cost about NGN 550 (EUR 1.20) each. The room sizes are around 3x3 metres as the smallest size and about 4x4m as the larger size. The windows, if any, are located only at the top for privacy and safety reasons. The tarpaulin can be around NGN 2000 - NGN 3000 (EUR 4.37 -EUR 6.56) in total, while the zinc sheets are NGN 750

(EUR 1.64) per panel. Each bacha costs about 20,000-30,000 naira. The price is not exactly fixed due to factors such as inflation and the size of the bacha.

Construction sequence



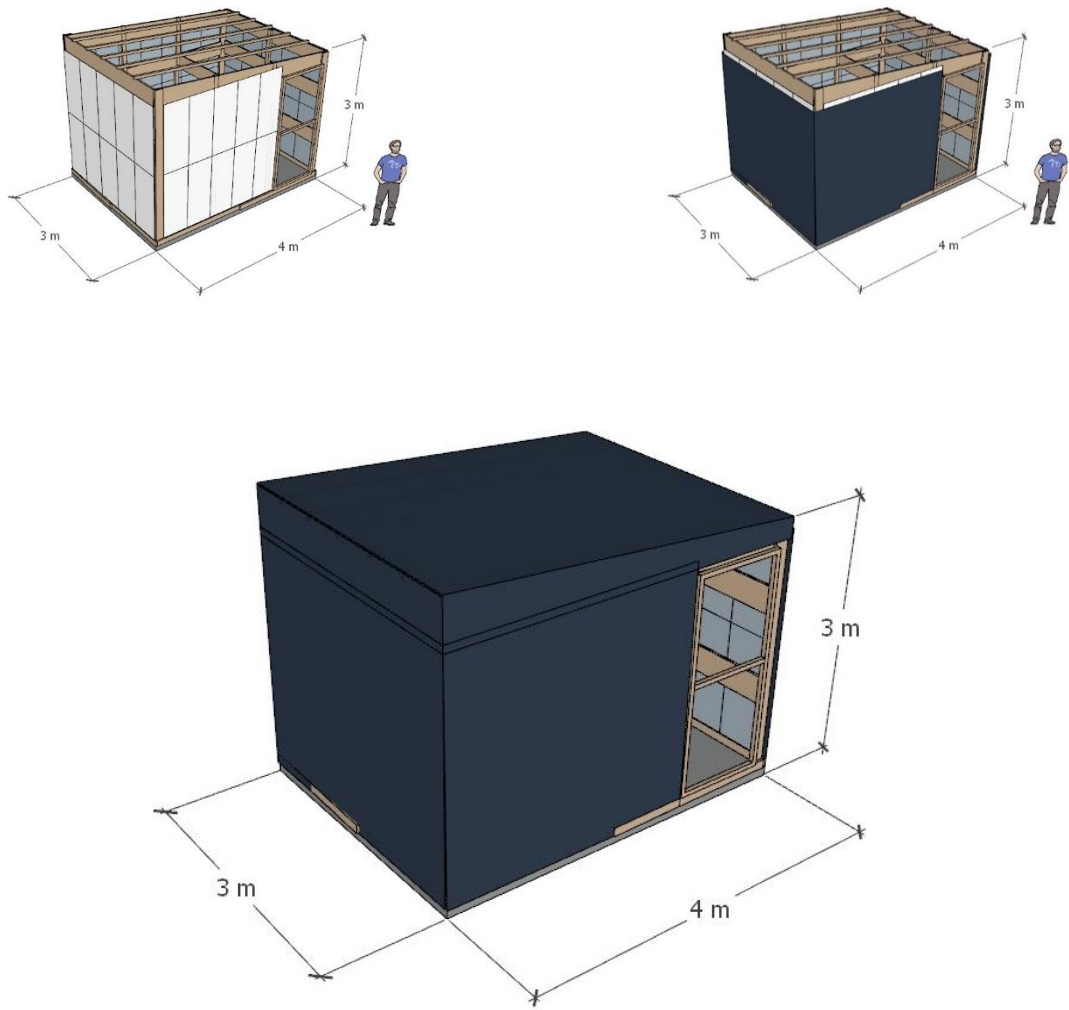


Figure 24: Bacha construction sequence



Figure 25: Existing bacha under construction



Figure 26: Bachas at the front of Kuchingoro IDP camp.

Connections:

The polypropylene sheets are connected through the use of nails. Sometimes the nails are bent to ensure that they are kept in place. Bamboo poles are connected through the use of rubber wires made from recycled car tyres. The zinc sheets are connected through a metal-capped nail to ensure connection by covering a larger area and stability.



Figure 27: Electricity supply wires connected by bamboo poles.

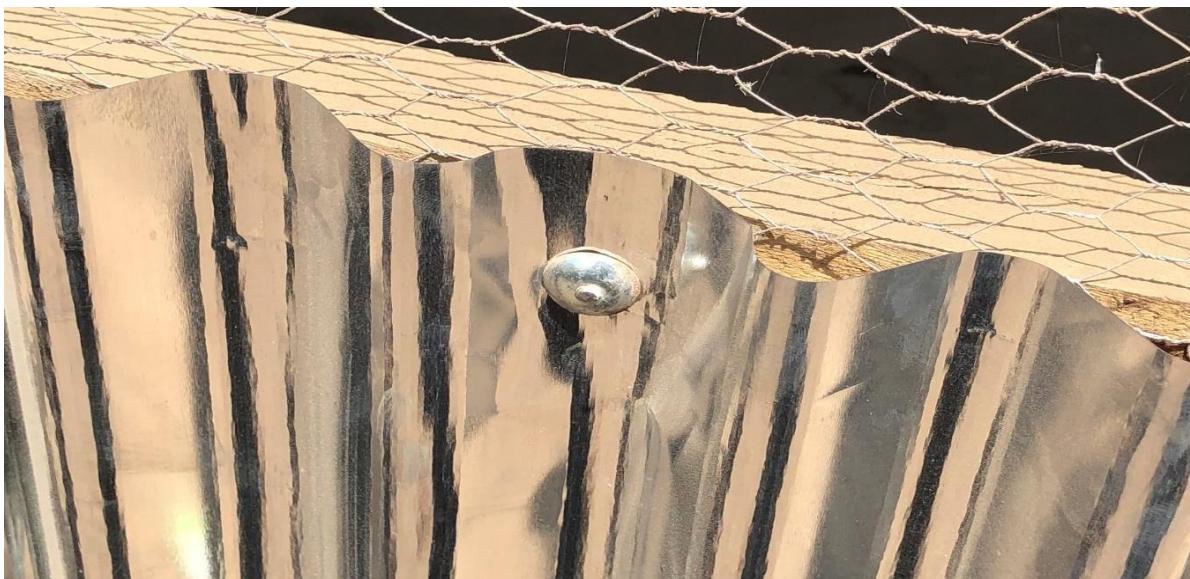
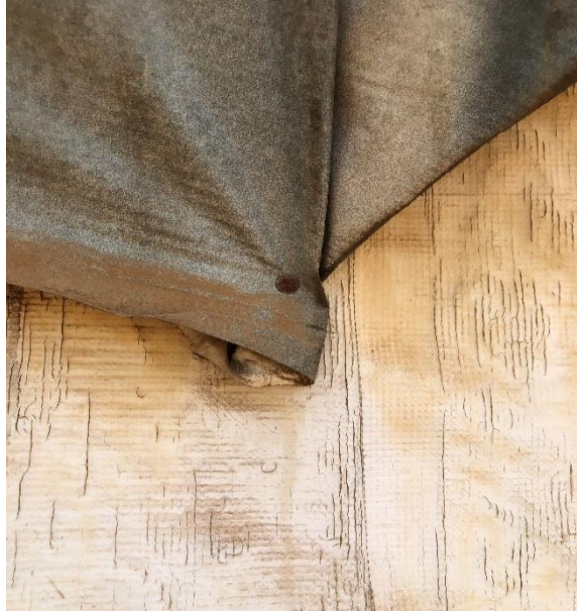


Figure 28: Nails connecting facade cladding materials in the camp.

ii. Gwoza and Bama IDP Camp, Durumi, Abuja

This is another IDP camp within Abuja. The accommodation is very similar to that in Kuchingoro IDP camp. They are also constructed with a wooden framework, and materials such as cement bags, sacks and tarpaulin are used as façade cladding materials. The camp is not organised, and the materials are not durable enough to protect the residents from harsh weather conditions. A semi-permanent structure in the camp is a school that is constructed using galvanised roofing sheets as cladding material and wood for the framework. The floor is made out of very thick concrete. A more permanent structure in the clinic building made up of concrete blocks, a zinc-coated sheet roof, a thick concrete base and a metal column for roof support.



Figure 30: Gwoza and Bama camp school (Edem-Nse. Y. G, Muhammad. I. B & Momoh. S. A. 2017).



Figure 29: Gwoza and Bama camp accommodation (Edem-Nse. Y. G, Muhammad. I. B & Momoh. S. A. 2017).



Figure 31: The clinic building in Durumi IDP camp, Abuja (Edem-Nse. Y. G, Muhammad. I. B & Momoh. S. A. 2017).

4.22 Other local construction methods.

Concrete blocks

The primary method of construction for housing in the urban regions within Abuja city is concrete blocks. The traditional techniques of mud construction were relegated to the background with the introduction of concrete slabs and blocks with the advent of the industrial period. The native dwellers of Abuja replaced the low-cost, comfortable and sustainable buildings with modern methods to express modernism, affluence and advancement. However, this mode of construction is costly for the low-income earners to build themselves and

even to rent. The climate is not suitable for the context but is the most popular form of construction within Abuja.



Figure 32: Man laying concrete wall (<https://structville.com/2018/08/how-to-calculate-the-quantity-of-mortar-for-laying-blocks.html>)

a. Compressed earth blocks

An alternative low-cost construction is the compressed earth blocks that are becoming more popular within Abuja. Stabilized or compressed earth bricks are made from a mixture of water, soil or earth and sand cement or lime as the stabiliser. The cement or lime percentage is in the range of 5-10%. Once it is mixed, it is then compressed into a high-density block and finally cured. According to a study conducted by Akinradewo, O. F., & Adedokun, D. O. (2020), The result shows that the cost per unit for interlocking brick was NGN 80.08 (EUR 0.18) while the cost per unit of concrete block was ₦347.20 (EUR 0.76). Interlocking earth bricks saves about 35% of the cost, while overall cost saving is about 58%. With about 67% savings being attributed to labour cost. Examples of these brick constructions are shown below.



Figure 33: Compressed earth block building Abuja (<https://www.shutterstock.com/nl/image-photo/abuja-brick-house-1228720180>)



Figure 34: Kaura market compressed bricks building (<https://www.google.com/maps/place/Kaura+Market,+Kaura,+Abuja,+Nigeria/@9.0066339,7.4557083,3a,75y,202.48h,85.25t/data=!3m6!1e1!3m4!1sSYumxj-5KHEWplXMkk7!4g!2e0!7i13312!8i6656!4m5!3m4!1s0x104e0cbef41ba9ed:0xfbf29>)

c. Indigenous building construction

Most of the residents of the camps are from the rural states of North Eastern Nigeria. It is essential to consider the housing strategies employed in their original settlements before being forcefully removed.

Within that context, clay is readily available; therefore, clay is mainly utilised as the building material. The locally processed clay is used to create clay bricks for the construction of the local houses.

These bricks are laid in a similar to conventional cement blockwork, which takes about 45 courses every day. The local builders also discourage the use of sand/ cement mortar to plaster the walls. Instead, clay mortar is favoured especially for protection from rainfall.



Figure 35: Traditional mud construction Borno (Mercy Corps, 2018).

In order to make a proper comparison between these different materials. A table is made to illustrate the different properties of the materials including:

- i. density [kg/m^3]
- ii. price/ m^2 facade cladding [naira]
- iii. weight [kg/m^3]
- iv. coefficient of thermal conductivity [$\text{W}/(\text{m.K})$]

- v. thermal resistance (excluded transition resistance) [m²K.W]
- vi. thermal resistance (excluded transition resistance) [m²K.W]

Building Material	Density (kg/m ³)	Price (Naira)	Thermal conductivity λ (W/mK)	Rc value (m ² K.W)	Rc value including transition (0.13+0.04)
1mm Zinc sheet	6500	1500	112.2	0.000008	0.17
10-12mm plywood	550	5500	0.13-0.35	0.03-0.04	0.20-0.21
0.50 mm polypropylene bags	950	600	0.33	0.002	0.21
150mm Compressed earth bricks (laterite/clay)	1600	1500	0.76	0.20	0.37
225mm Concrete block	1800	2750	0.80	0.28	0.45

Table 4: Comparison of housing material in Abuja

From the table above, the materials with a higher thickness show increased resistance. The zinc sheet has the highest thermal conductivity and the lowest resistance; therefore, it is the worst material for construction in these camps.

4.3 Bio-climatic design strategies for Nigeria

In tropical climates such as Nigeria, the primary objective is to retain a comfortable indoor ambient temperature. Therefore, design strategies should seek to follow two main goals

- Minimising heat gain: This is the most important goal for both hot & humid and hot & dry climates. This goal informs aspects of the building such as the orientation window design shading, thermal insulation and many others
- Promoting heat loss: In hot climates, it is prudent to design so that heat stored in a building during the day can be released at night. This goal informs a lot of passive cooling methods like evaporative cooling and thermal mass.

The Federal Ministry of Power, Works and Housing in Nigeria released a guideline for building efficiency, which expounds on the strategies for housing in Nigeria. According to this guideline, the design of a building using bioclimatic strategies in tropical regions usually follows this process.

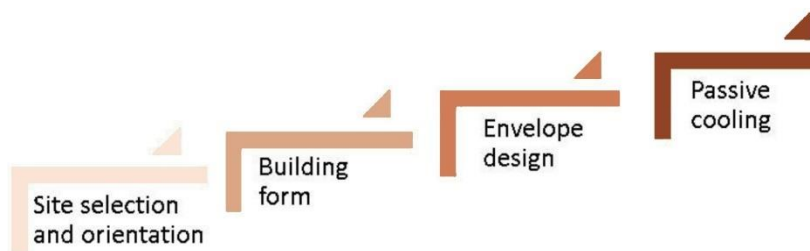


Figure 36: Bioclimatic strategies sequence. (Arup (Madrid & Lagos offices), 2016).

a. Site selection and orientation:

The energy balance of buildings is primarily determined by the building's orientation towards the sun and prevailing winds. This will affect solar gains and air movement within the buildings. When choosing the direction of a building, the microclimate around the building should be improved. Trees should be left around the building as much as possible because they provide evaporative cooling and shade to facilities. Solar heat gains are brought about by direct solar irradiance. Thus, windows should not be placed directly in front of sunlight. Nigeria is located near the Equator; therefore, the sun path does not vary much over the year. This is illustrated in the diagram below.

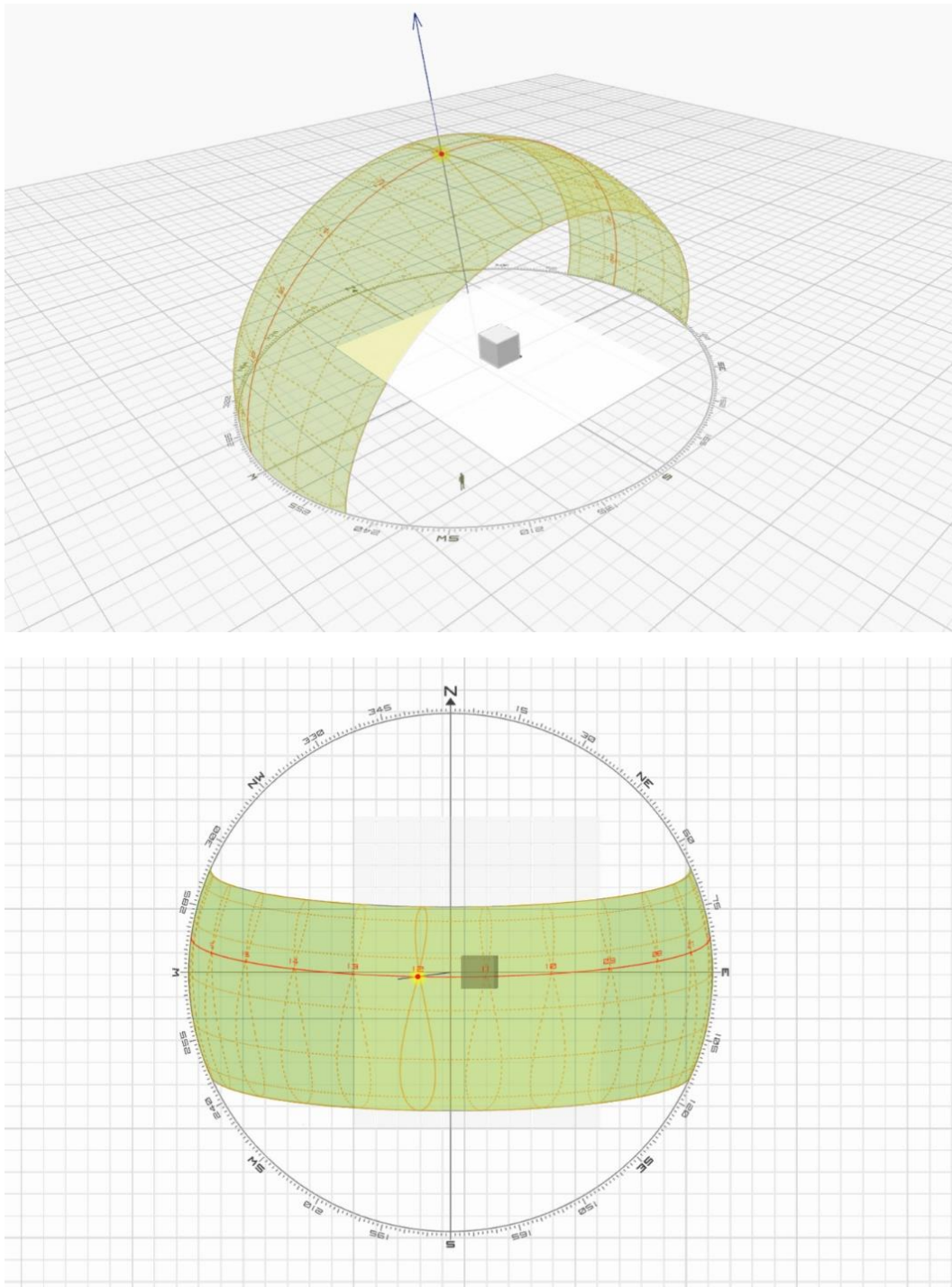


Figure 37: Sun path for Abuja, Nigeria. (<https://drajmarsh.bitbucket.io/sunpath3d.html>)

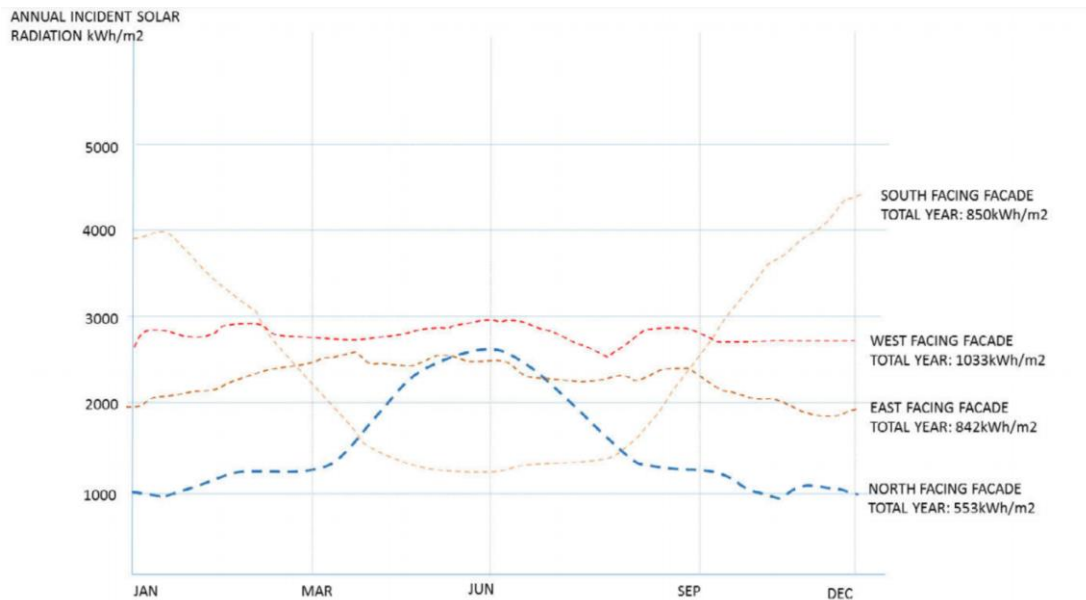


Figure 38: Annual incident radiation for Nigeria. (Arup (Madrid & Lagos offices), 2016).

The relatively stable sun path allows for easy orientation optimisation and shading. The roof has the highest solar load because it has a higher solar altitude; thus, roof lights should be avoided as it is the easiest path for the housing to heat up. The south-facing façade receives constant radiation all year long; However, the high solar angle ensures that shading or overhangs can prevent direct sunlight from reaching the façade. The North facing façade exhibits the lowest amount of incident solar radiation, but it receives sunlight in some months of the year. The east-facing façade receives almost the same total radiation as the south-facing façade, but the low sun angle makes it challenging to stop the sunlight from hitting the façade. The west-facing façade has the highest solar irradiation with low sun angles all afternoon. From these results, it is clear that openings on the east and west-facing windows should be avoided, while windows on the North and South should be placed with appropriate shading.

The building should also be oriented towards the direction of the wind. The prevailing winds are the South-South, and southwest winds.

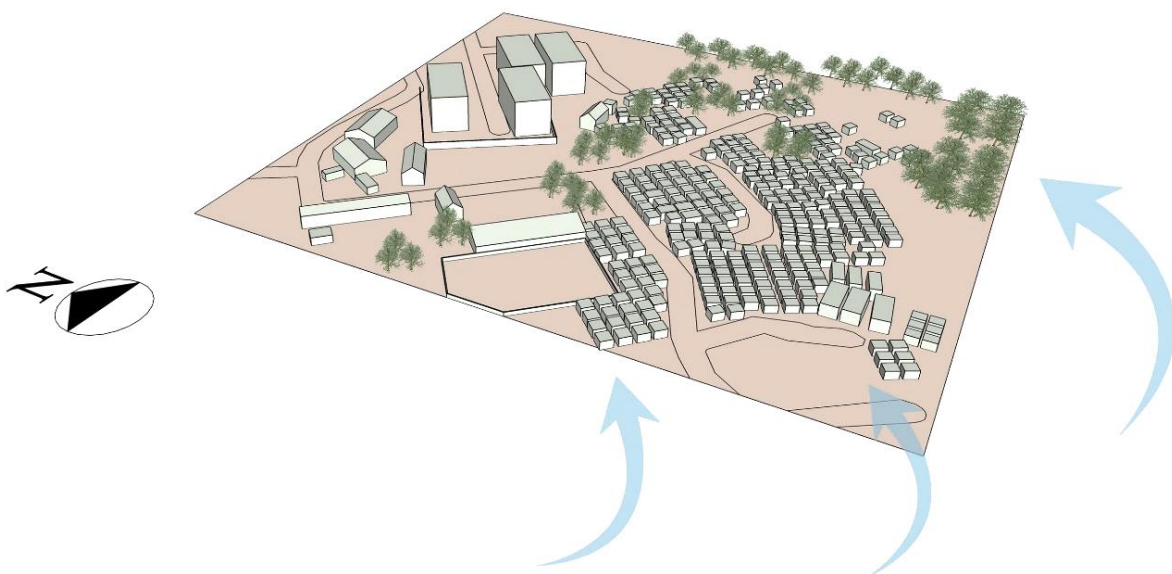


Figure 39: Axonometric view of the site showing the orientation and wind direction

b. Building form and geometry

The building form and geometry strategies mainly deal with room configuration, outdoor areas and volume. The first strategy is to make the geometry as compact as possible by proportionally reducing the outer skin area in relation to the volume. Compact shapes like cuboids exhibit lower heat gain than extended forms with similar volume. This is because a lower surface-volume ratio results in lower cooling demand.

Another strategy is the use of buffer zones. Buffer zones are not regularly occupied; therefore, the higher temperature outside normal thermal comfort levels are satisfactory. A conventional method of doing this in Nigeria is shaded circulation spaces, verandas or balconies around the structure. This would be useful, especially for the South, West and East facing facades.

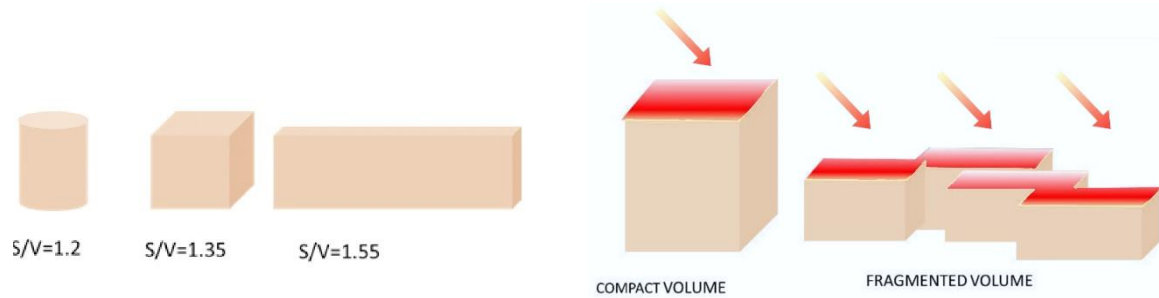


Figure 40: Building geometry surface/volume calculation and solar load (Arup (Madrid & Lagos offices), 2016).

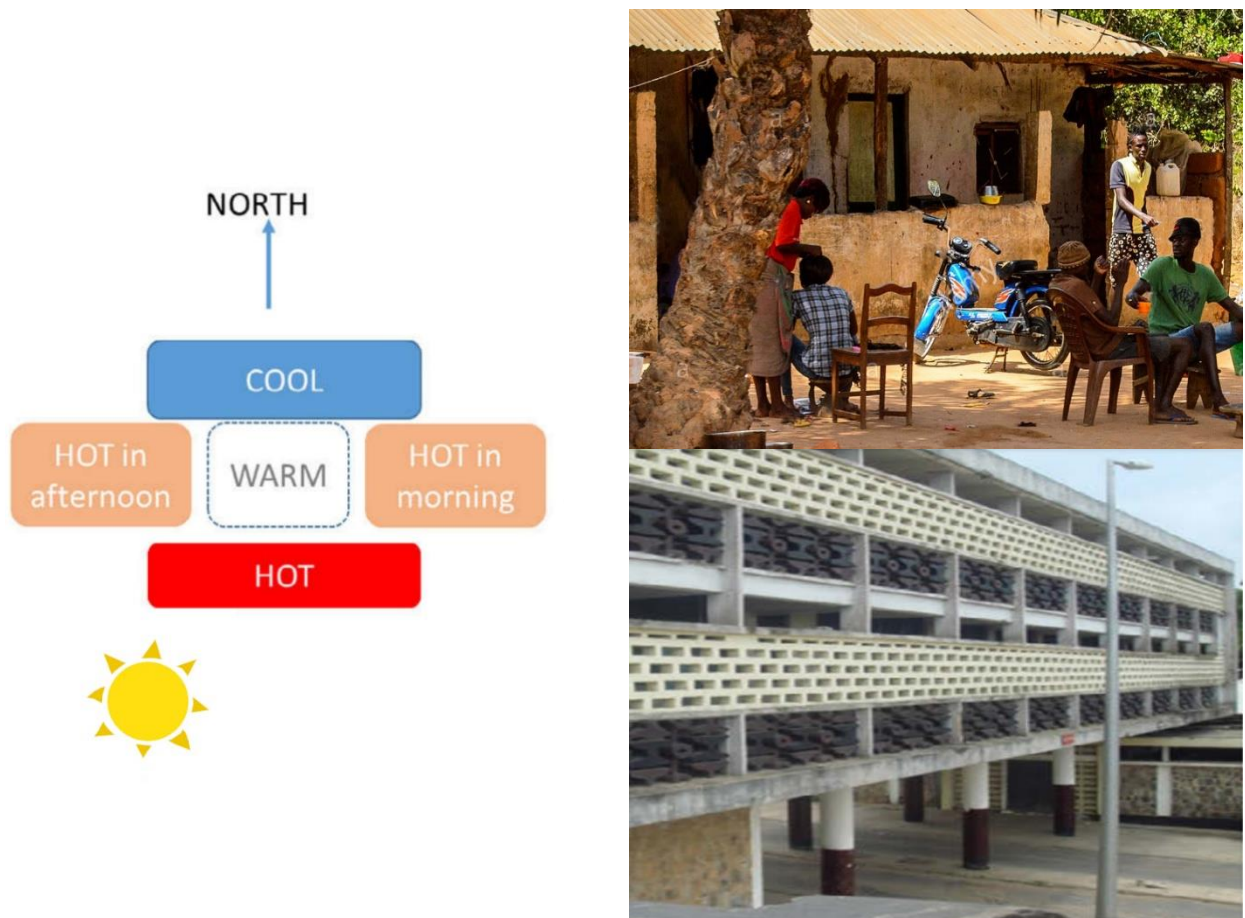


Figure 41: Buffer zone diagram and applications in the Nigerian context (Arup (Madrid & Lagos offices), 2016).

Natural ventilation is another way to help cool down the building. There are different rules of thumb for naturally ventilated openings. The most basic form of natural ventilation is single-sided openings. However, these are only suitable when the room's depth is at least 6 metres long or 2.5 times the height of the ceiling. The more effective form is cross ventilation because the pressure of the wind will push the air through the structure. In this case, the room depth can be as much as 12m or more (5 times the height of the ceiling).

Other natural ventilation options involve the use of light wells and atria, but this has to be designed carefully as roof lights increase the solar load in the building.

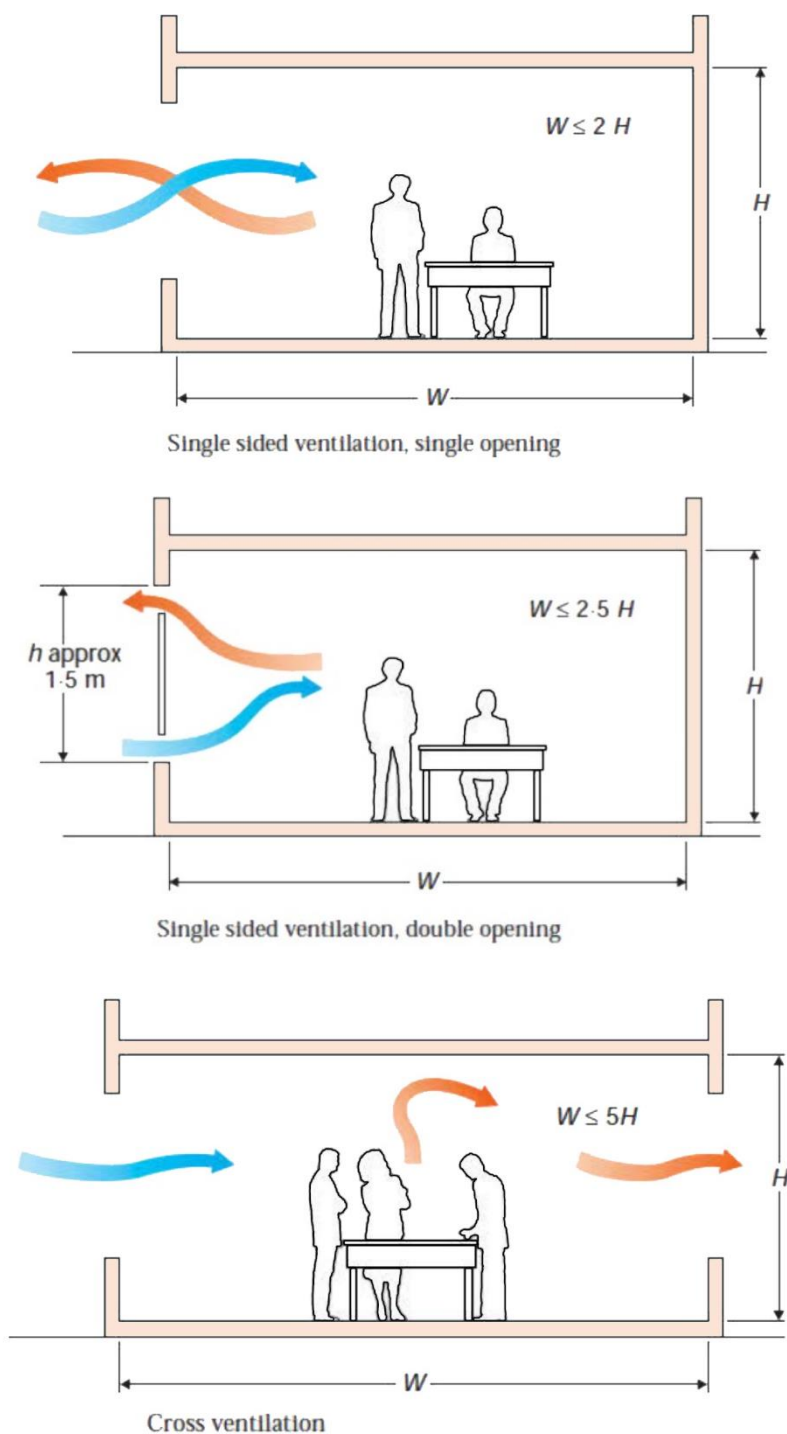


Figure 42: Natural ventilation strategies (Arup (Madrid & Lagos offices), 2016).

c. Building envelope

A building can reduce the amount of solar load significantly by the use of shading elements. South and North-facing windows can easily be shaded with overhangs and horizontal shading due to the high solar angles. The west and east facades have shallow solar angles, and sunlight gets to the building almost perpendicularly; thus, windows should not be placed on this side. When the solar angle is determined, the appropriate solar shading overhang can be calculated using the formula below.

FORMULA FOR OVERHANG CALCULATION

Where L_s = Solar angle
 hr = overhang width
 hw = distance between the window start and gutter
 L_x = angle for overhang calculation

$L_x + L_s = 90$
 $L_x = 90 - L_s$
 $\tan L_x = hr/hw$
 $hr = hw * \tan (90 - L_s)$

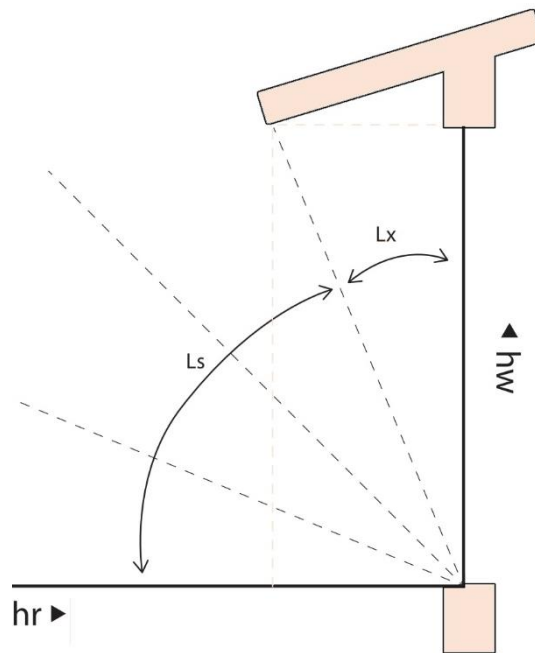


Figure 43: Shading overhang calculation

The design of the buildings in the IDP camp is very simple; thus, it is improbable that than adaptive overhang would be available throughout all the months for optimum climate conditions. The solar angles are similar throughout the year, as established earlier. So, if the overhang is sufficient for the lowest sun angles from horizontal to avoid all direct sunlight between 9 am and 3 pm, it should be suitable for the rest of the year.

The table below shows the lowest sun angle for Abuja to allow approximate overhang size for the North and South facing windows.

Façade orientation	Due North	20° E/W of North	Due South	20° E/W of South
Abuja (Lat 6°N)	73°	62°	57°	49°

Table 5: Lowest sun angle from horizontal to avoid all direct sunlight between 9 am and 3 pm (Arup (Madrid & Lagos offices), 2016).

d. Passive cooling

Once thermal gains have been minimised by implementing the strategies mentioned earlier, orientation building form and envelope design, the next step is to employ strategies to increase indoor comfort and promote heat loss. An effective way to do this is through night cooling thermal mass. In tropical climates, thermal mass can absorb and store heat during the day and release the accumulated heat at night. For this strategy to work, a high mass and large area are required, such as tiled floors, heavyweight stone, concrete, etc.

In addition, this mass needs to be left exposed within the room. In the daytime, the mass absorbs the heat, preventing the internal temperature from rising above comfort levels.

During the night, the outdoor temperature is much lower, and the outdoor air ventilates the space to remove the heat. A general rule of thumb is that the temperature difference between day and night should be above 6°C to ensure that night cooling is adequate; 10 °C is the most optimum temperature difference. Thermal mass in Nigeria is more effective towards the North, where the climate is hot and dry. Abuja is located in the North-central region, and the daily temperature differences are between 6-15 degrees all year round, which is sufficient for passive cooling. The thermal mass also needs to be protected on the outside for it to be the most effective. Insulation should not be added to the thermal mass inside of the building because it will reduce its efficiency. Furthermore, adding false ceilings, carpets, or other unnecessary construction may reduce the benefits.

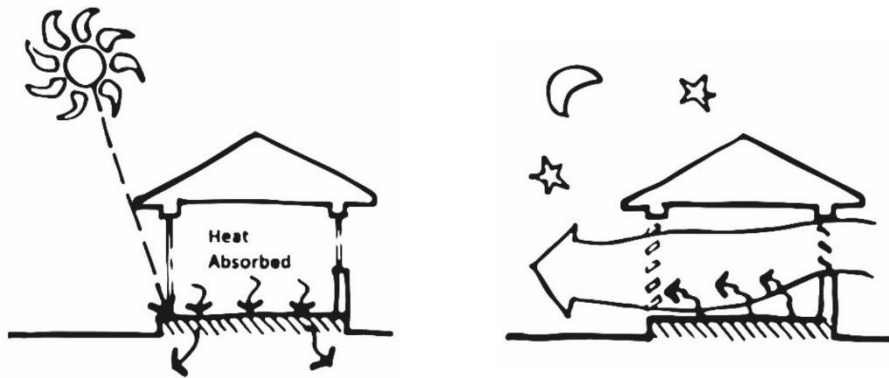


Figure 44 High thermal mass floor concept (Arup (Madrid & Lagos offices), 2016):

A general summary of the general climate strategies stated by the guideline is shown in the table below.

Key passive strategies	Hot & dry
Climatic conditions	<ul style="list-style-type: none"> • High ambient temperature and solar radiation levels • High glare from direct and reflected sunlight • Dust storms
Microclimate design	<ul style="list-style-type: none"> • Compact forms • Shade and shelter for public spaces • Glare control: roughness and low reflective colours • Evaporative cooling: by strategic inclusion of vegetation • Windward location close to water bodies if feasible • Narrow winding roads and alleys, and mixed building heights
Building Design	<ul style="list-style-type: none"> • Windows facing mainly north and south with overhangs/ external shading • Compact geometry reducing skin area • Buffer zones and thermal zoning • Daylighting zones • Night cooled mass systems • High thermal mass • Exterior insulation for reducing heat gains during the day

Table 6: Key passive strategies for a hot and dry tropical climate (Arup (Madrid & Lagos offices), 2016).

Energy efficiency in tropical regions can be improved by using the "Solar Fruit Tree" strategy Lechner (2014). It shows different major solar strategies placed at different heights in order of importance to the overall design. The principle is that the low-hanging fruit strategies are low cost; thus, money can be saved, and the complete structure's initial cost is reduced. This strategy is illustrated in the figure below.



Figure 45: Solar Fruit Tree tropical climate Strategy (Lechner, 2014).

This strategy shows that building orientation to passive solar energy is applicable for the design context.

5

Plastic waste in the
Nigerian context



5.1 Waste in Nigeria

One of the major global environmental challenges facing our world today is the menace of plastic waste pollution. Plastic is a non-biodegradable material which causes environmental hazard on both land and sea. Nigeria is one of the primary importers of plastic into the African continent. As a result, plastic waste has led to a rapid increase in environmental pollution, and waste management is one of Nigeria's most significant challenges. According to research, most of these wastes are plastics and polymers, which are challenging to manage because they are non-biodegradable. Additionally, less than 12% of plastic in Nigeria are recycled, with about 80% ending up on dumpsites or landfills. Therefore, there is a real need for the building industry to find an alternative use to these plastic wastes.

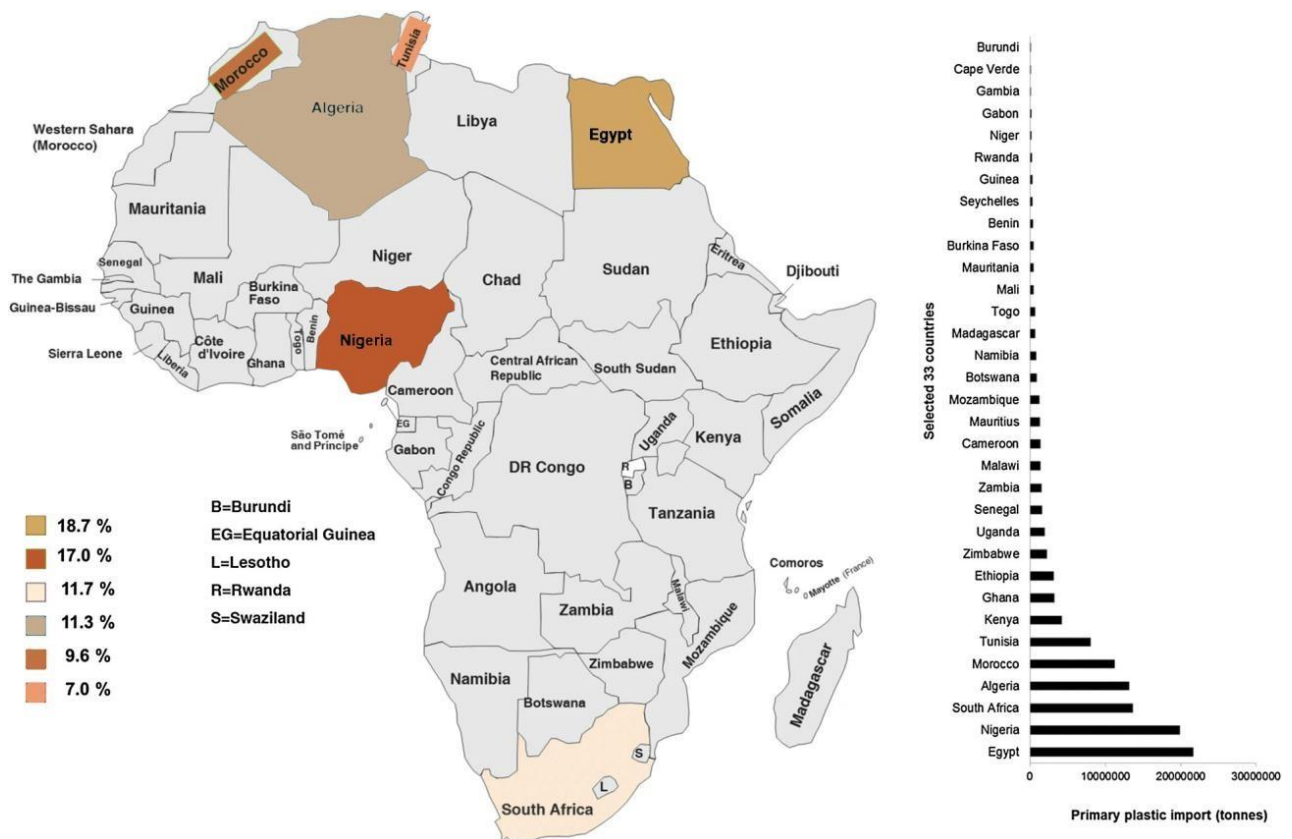


Figure 46: Percentage of plastic importation Africa (Babayemi et al., 2019)

Urbanisation in Nigeria has become a significant contributor to the high volume of plastic waste produced and scrapped yearly. Coupled with the noticeable absence of plastic waste treatment, nationwide negligence seems hydra-headed for all intents and purposes. In Nigeria, around 80% of residents in cities, towns, and villages are in charge of disposing of their own waste. This is because of a lack of waste collecting and disposal services across the nation. By the same token, the struggling infrastructure does not make the job easier for waste collection and management agencies. The absence of a privatised waste management is also an issue. This is because the government is incapable of adequately managing waste as it is not incentivised to be innovative in its processes (Ike et al., 2018).

Additionally, important basic physical structures such as good roads and road networks are not reliable. This makes it nearly impossible for the already scarce waste management vehicles to access residents' homes.

Finally, according to Babayemi (2009), most people are uninformed about the availability of waste management services. This has led to people dumping their waste just outside their homes or on illegal dumping grounds.



Figure 47: A dumpsite in Abuja (Babayemi et al., 2019).

Consequently, most Nigerians are tasked with having the fate of their waste in their own hands. According to Sha'Ato et al. (2007), waste composition research shows that household waste accounts for about 40-60% of urban waste. In the city of Makurdi in Benue state, the produced waste was over 80% from households. According to Iman et al. (2007), in the master plan for Abuja, the government was allocated 2% for use, suburban development received 49%, while recreational/open areas and auxiliary areas secured 32.5% and 16.5%, respectively. This highlights the critical role that the households play in waste across the city, and the difficulty of circumventing household waste increase with an increase in urbanisation.

5.2 Plastic waste in Abuja

It is increasingly difficult to speak on the waste issue in Abuja without focusing on its major contributors (households), how they have been organised and the variations in their contributions based on location. The residential arrangement of the city of Abuja has been predestined from an early time. It relies heavily on four operational phases (areas) being developed over 250 square kilometres. These phases are separated into districts, and these are further divided into neighbourhoods. The first phase consists of seven districts viz: Wuse I, Wuse II, Garki I, Garki II, Central Area, Maitama and Asokoro. These almost serve as geographical beacons when travelling around the city. The second phase consists of 14 residential districts, while the third phase consists of 11 districts. The fluctuating and degenerating economic situation aided in the escalating encampment in the city's suburbs, also known as satellite towns.

These towns are generally characterised by being densely populated with a shortage of basic amenities and decent infrastructure. Usually, impoverished and low-income earning workers make up the suburban population.

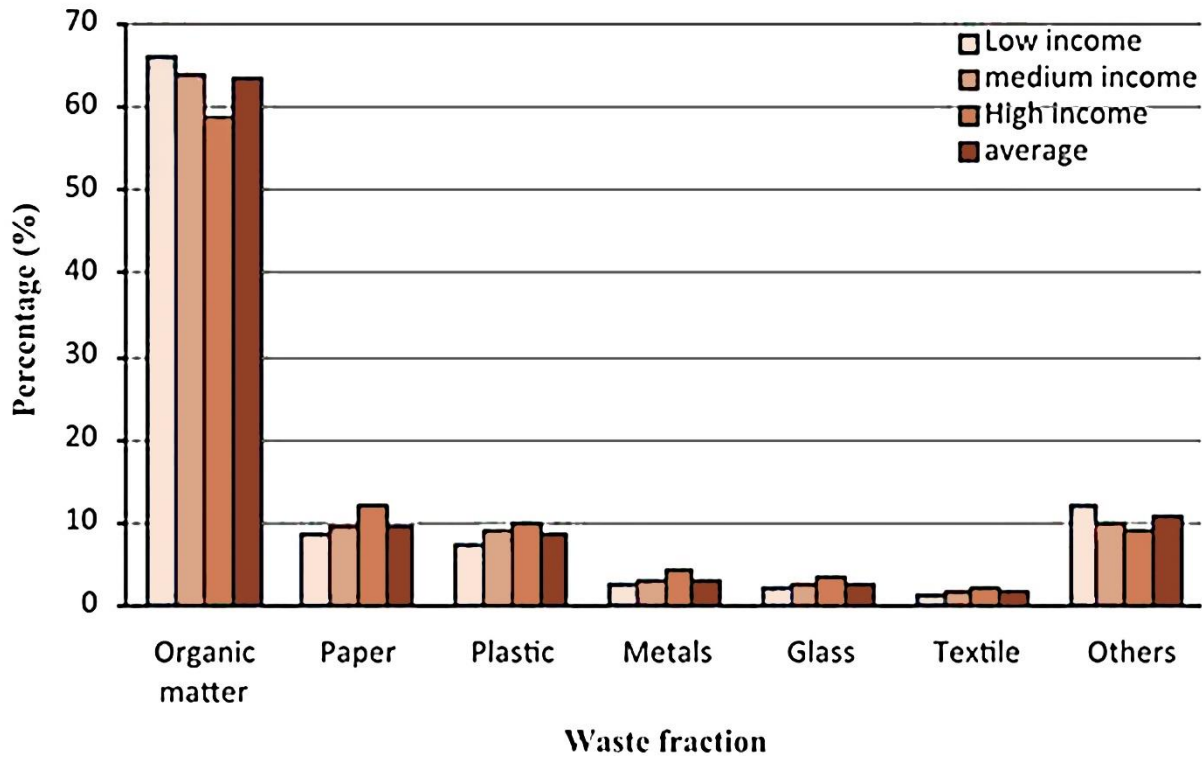


Figure 48: Average waste composition (percentages) for three socio-economic groups (Ogwueleka, 2013).

An extensive study by Ogwueleka (2013) showed that plastics are the second most generated waste, only behind organic and paper. It also highlighted the socio-economic impacts of waste generation, and the range of the high, medium and low-income earning household are from 7%-10%. The high-income earning household has a 10% grade for plastic waste production. Nevertheless, due to the non-biodegradable nature of plastic, its effects continue to be treated with the utmost importance on the environmental front, and those effects are not less impactful in Abuja. The most recent study classified general waste in Abuja as around 1191.9 tons, and plastic accounts for 15.27% of that amount which is 182 tonnes or 182,000 kg.

5.3 Plastic Waste categorisation

As previously stated, plastic waste serves as the greatest threat to land and the environment in Abuja, and it is relatively generated uniformly across all households. The effects of plastics may not be immediately apparent, but contaminated plastics can release poisonous material in the soil, which have a propensity of flowing into underground water bodies. This could potentially be harmful to anybody consuming it. Plastics are generally categorised into two types, thermoplastics and thermosets. Thermoset plastics contain polymers that are cross-linked together, thus creating an irreversible bond. This means that it is impossible to remelt them; once they take shape, they will be solidified forever. Due to the nature of thermosets, they are not suitable for recycling. Thermoplastics are made up of polymers that change state by becoming soft when heat is applied and harden when cooled down. Thermoplastic items can be heated and cooled down multiple time; thus, they are suitable

for recycling. Luckily about 80% of plastic generated worldwide are thermoplastics which means they are recyclable. Thermoplastics (which will be referred to as plastic from now on) can be further divided into subcategories based on their general properties and structure. They are recognised by their number or name, usually embossed or printed on the plastic product. The most common types of plastics are shown in the image below.

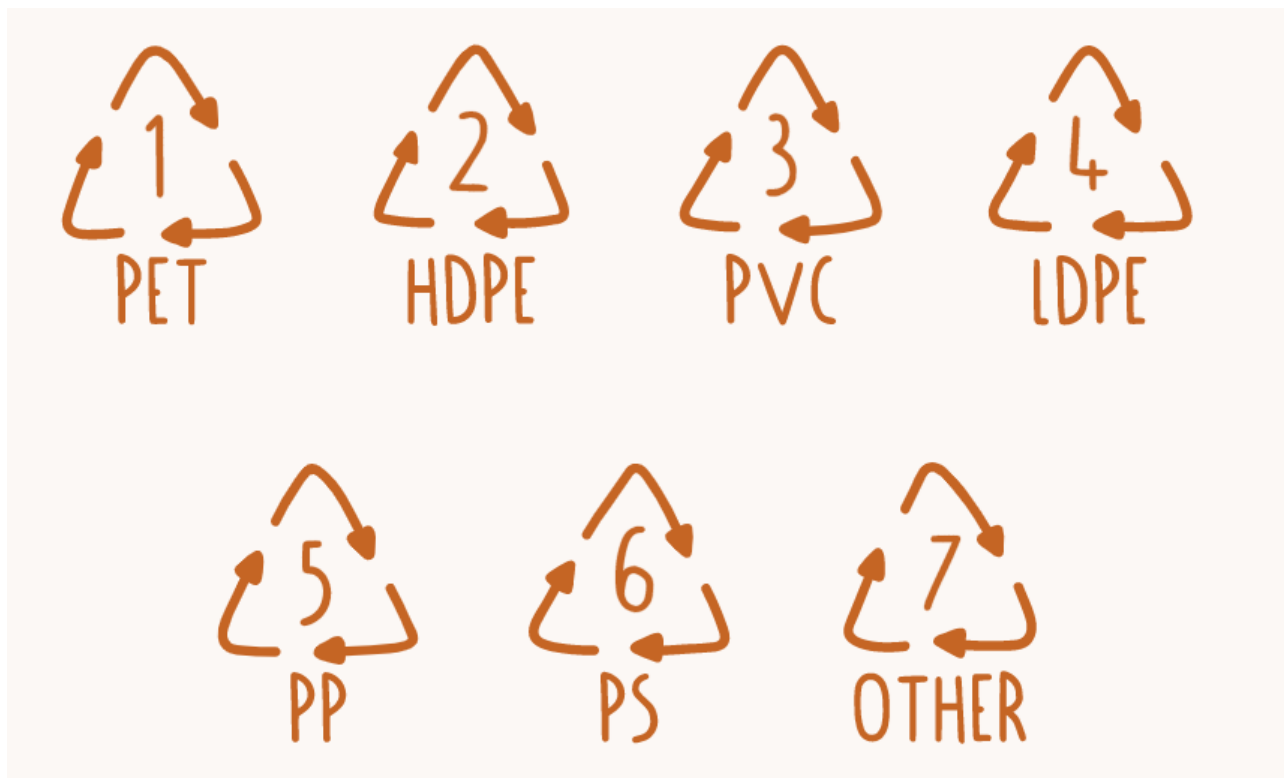


Figure 49: Thermoplastic categorisation (<https://community.preciousplastic.com/academy/plastic/basics>)

The major suspects of plastic waste in Abuja are plastic bottles, sachet water and plastic shopping bags. Due to their single-use nature, they are perfect candidates for being disposed of without much thought. Plastic bottles are usually made from polyethylene terephthalate (PET). Sachet water is made from LDPE, while plastic bags are made from HDPE.

5.31 Low-Density Polyethylene (LDPE)

Polyethylene (PE) is a thermoplastic, meaning it can be reshaped or -moulded by heating it. Sachet water is an extremely important plastic waste in Abuja and Nigeria as a whole. This is because of its consumption rate. A study by Edoga et al. (2008) suggests that about 70% of Nigerians take the 500mL sachet water a day, which amounts to around 140 million of these plastic sachets being disposed of daily. Due to the organic chemistry of these plastic sachets, they are tough and are resistant to impact. They do not allow moisture through them and do not transfer chemicals into the products they hold.

5.32 High-Density Polyethylene

'HD' means 'High Density'. The density of HDPE is relatively high, which gives it a lower insulating capacity compared to LDPE, but it also makes it structurally stronger. HDPE is more often applied for outdoor use due to its better resistance to UV sunlight. A lot of the plastic bags used in many of the stores are made from HDPE. Landfilling materials made from HDPE, in general, is not an effective method of disposal as it is undoubtedly

non-biodegradable. However, according to Thomas (2012), HDPE is straightforward to recycle due to its durability. It is also more cost-effective than reverting to new HDPE.

5.32 Polyethylene terephthalate (PET)

These are not as tough as HDPE, and so they are lightweight and are usually used in making plastic bottle bodies and plastic bags for grocery shopping. These plastic bottles and plastic bags combined contribute just as much daily plastic waste generation as sachet water or plastic bags in Abuja, and this poses an even greater threat to the environment than just land pollution. This is because the constant single-use and disposal of these products mean more PET has to be produced. Its production process causes considerable amounts of greenhouse gases to be dispelled into the atmosphere (Thomas, 2012).



Figure 50: Plastic bottles and bags in a gutter (Kehinde, 2020).

Figure 50 presents yet another major issue caused by plastic waste disposed of inappropriately. Disposal into gutters leads to drainage blockage, and this escalates into minor flooding in times of heavy rain. Due to PET, LDPE and HDPE being non-biodegradable, these products will certainly last in these gutters until they are moved to a different location.

5.4 Plastic waste management

In relation to different materials widely utilised and disposed of, such as glass, paper and ceramics, plastic waste products are the least recycled. There is just over 10% of plastic waste recycled annually in Nigeria, while about 80% are landfilled or end up in dumpsites (Babayemi et al., 2018). This is due to the poor treatment of plastics. Plastic waste and solid waste management continue to be a complex problem facing the environment. It is

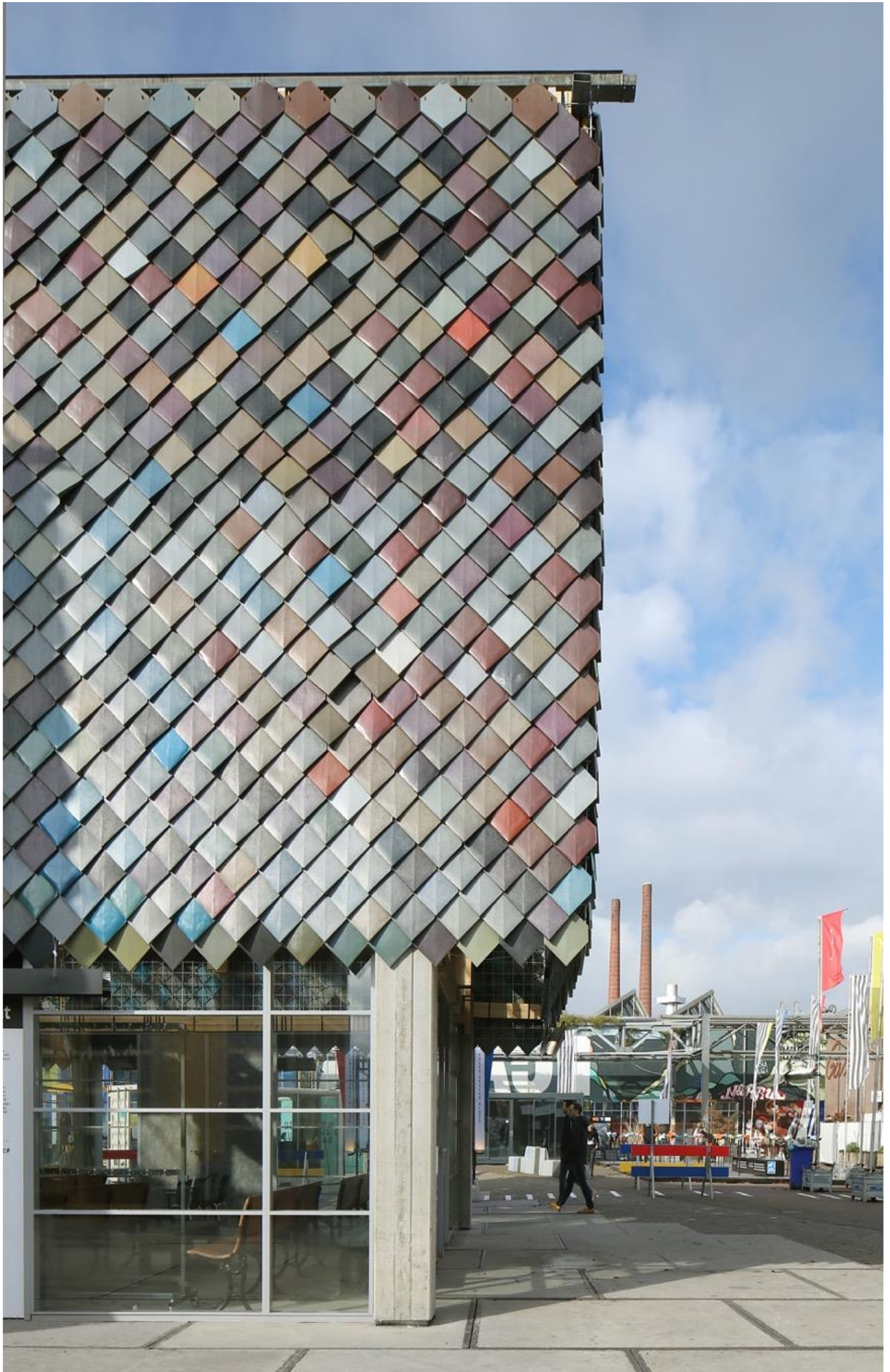
believed that about 4.4 million tonnes of solid wastes are mismanaged yearly in the African continent (Jambeck et al., 2018). This number is only growing. An efficient waste management system is contingent on definitive data and precise planning tools. According to a study by Iman et al. (2008), it is believed that an average of 0.565kg/capita of waste is produced a day. Adjusting for inflation, this amount is likely to have increased over time. With the increase of monthly minimum wage from around N7,500 (\$47) to N18,000 (\$112), it is expected that spending habits experience change. According to a study by Dennison et al. (1996), there were larger amounts of waste produced after a better socioeconomic situation was afforded to a people compared to the initial circumstance. As previously stated, proper management lies in a near perfect system. Nnaji (2014) suggests that a manifold of stages be employed, specifically collection and transportation of produced waste, directly sorting the trash, and treatment: recovery and disposal.

The Reduce, Reuse and Recycle strategy is mainly targeted at plastic waste as recycling is the most capable of dealing with these products. Unfortunately, the infrastructure for recycling plastics in Abuja is not extensive enough to deal with the amount generated every year. Nonetheless, the ideal method of dealing with plastic waste from a socioeconomic and environmental perspective is recycling. It could be the only way for Abuja to sort out the problem.

- i. Primary recycling: This comprises waste that does not make its way to the consumer. This means they are from manufacturing companies, and it is their responsibility to deal with plastic products. However, most of the generated plastic waste products come from consumers. Nonetheless, the state government in Abuja must mandate these industries to recycle their generated plastic waste.
- ii. Secondary recycling: This is the process of working with post-consumer plastic products and would have significant impacts on the amount of plastic waste in Abuja. The process is relatively easy and cost-effective. According to Al-Sabagh et al. (2016), secondary recycling consists of sorting, shredding the plastics into fragments, rinsed and dried. The responsibility will be on the state government of Abuja to ensure that the infrastructure for this is provided. An alternative solution would be to incentivise private recycling companies and agencies to delve into secondary recycling.
- iii. Tertiary recycling: This is the application of chemicals in the recycling process and is applied to post-consumer plastics. PET and HDPE are formed of polymers, and the concept of chemical use is for the depolymerisation of the products into monomers (Sittrop). According to Awaja & Pavel (2005), the process requires expensive chemicals and would not be convenient in smaller towns and remote areas. This makes it difficult for satellite towns in Abuja to implement this recycling method and isolates a significant amount of plastic generating population.
- iv. Quaternary recycling: This is the process of incinerating plastic waste products. It is usually the least desirable recycling method due to the release of greenhouse gases, which negatively affects the environment. Energy can be retrieved from the heat; however, the efficiency is low.

6

Case studies of
plastic as a building
component



6.1 Precedents of plastic building components

a. Bottle bricks:

Plastic Bottle Bricks are basically plastic bottles that are densely packed with filler materials such as plastics, compacted sand or any non-organic substance. This creates a solid and dense brick used in conjunction with a filler adhesive substance such as cement, sand, or adobe for construction; thus, it serves a similar function as an average brick or traditional earth blocks. It is a versatile form of building as it can be created as long as there is a plastic bottle and a filler material. It can be used in conjunction with other bricks, wooden beams and other construction methods or materials even if they do not serve as the primary structural elements.



Figure 51; Plastic bricks (Engineering For Change | By Engineers, For Everyone, 2020).

b. Bloqueplas:

These are interlocking blocks that are made from recycled PET (Polyethylene terephthalate). It is a dry form of construction because the bricks do not require a mortar between them due to the tongue and groove stacking system. All that is needed when assembling the walls is a hammer. It is produced and supplied by a company called Grupo Ectoplasm situated in Colombia.

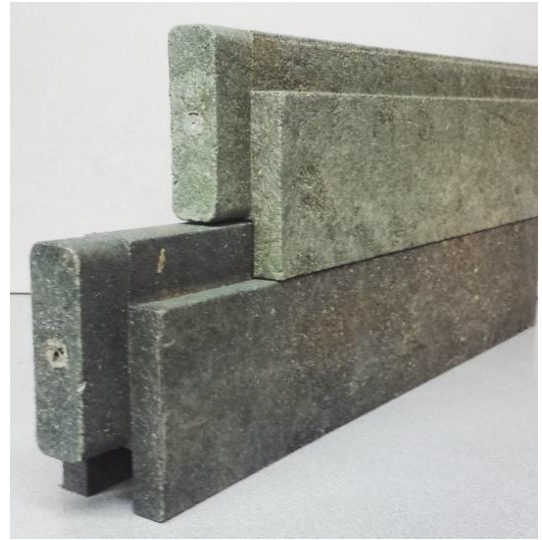


Figure 52: Bloque plas interlocking bricks (Engineering For Change | By Engineers, For Everyone, 2020).

c. Ifrique Collections and Designs floor tiles by Intissar Bashir Kurfi

An existing system for interlocking tiles made from soil and recycled plastic water sachets in Abuja is already available. Nylon material is sorted, cleaned and dried. Then it is melted in a fire drum and then mixed with sand. It is put in moulds and left to dry. This is all done manually. Each tile takes one kg of nylon, and it can be customizable in colour and shape. I met with the creator of these bricks, and the interview went as follows:

Q. What kind of plastic is collected?

A. LDPE is mixed with sand, particularly from waste pure water sachets.

Q. How much is Plastic is bought from members of the community?

A. NGN 30-70 naira per kg (EUR 0.060- 0.14). The best plastic can be as much as NGN 100 (EUR 0.20). It depends on the quality of the plastics, LDPE. They are bought from a different place and then taken to the site in Abuja.

Q. What is the general manufacturing process of these bricks?

A. Get the clean plastic because there is no machine to sort them, shred them, melt them, weigh them, and mix them with other sand and pigment materials. Then they are put into the mould to dry, and they are not fired at all. It takes about 30 minutes to dry, and it can be laid immediately. It complies with the building regulations, but it has not undergone major fire tests.

Q. How much are these plastic bricks?

A. NGN 5000 (EUR 9.95) per square metre (Normal conventional concrete on is NGN 3000 (EUR 5.97) per square meter, Berger NGN5000-7000 (EUR 9.95-13.93). So, the pricing of this plastic compares to the strength of the higher quality bricks (Berger).

Q. What are the challenges you face?

A. The machines have to be designed specifically for the design; most of the mixing is done manually. There are plans to build machines here, then maybe order a machine from elsewhere later on. The Machine should be more environmentally friendly to reduce carbon emissions and for the safety of the workers. There is always manual labour available. The better the plastic, the more expensive it is. The profitability is minimal because

the raw materials are costly, the washing and the sorting machine would make it cheaper. Most of the constraints is finding good plastic, and the labour cannot be paid lower because of the buying cost of the plastic.

Q. What is the end of life of these bricks?

A. The plastic can be completely remelted and can be done over and over again. The offcuts from the bricks are always re-melted and added to a new batch, so there is little waste generated.

The major conclusions from this interview are:

- There is no particular ratio of sand to plastic available, and it is not a standardized process.
- There was no fire test conducted.
- It complies with the building requirements for its application but only for use on the ground.
- Labour intensive approach may work as there is always labour available.
- Washing, sorting and shredding machines would reduce cost overall.
- The cost would be reduced majorly if there was enough sensitization around plastic waste. Plastic collection from major housing areas, e.g., estates within Abuja, would provide sufficient raw materials for bulk production.



Figure 53: Ifrique Collections and Designs bricks (Intissar Bashir Kurfi)

d. Mod roof:

Swad Komanduri and Hasit Ganatra developed MODroof panels. Agricultural waste and waste packaging material is used to produce a modular roofing system. The packaging material is shredded and compressed together with reinforcement which functions as waste fibre. After this, the panels are subjected to a high temperature and subsequently left out to dry. Once the shape is achieved, the tiles are made waterproof by the addition of a coating. The interlocking panels have better insulation properties than the regular iron corrugated sheets.



Figure 54: MODroof (Engineering For Change | By Engineers, For Everyone, 2020).

e. Pretty plastic upcycled tiles:

This is a company set up by Hester van Dijk, Peter van Assche, Reinder Bakker. They use recycled PVC to produce cladding sheets used for indoor and outdoor cladding. In 2019, the pretty plastic tiles received a fire certificate class B approval which means it is very difficult to burn; this complies with the NEN-EN 13501-1.



Figure 55: The Circle House in Aarhus (<https://www.prettyplastic.nl/>)

f. Moladi:

This building system involves the use of plastic injection moulded elements used for cast-in-place continuous housing structures. It provides affordable moulding for people using components that can be easily joined

together by unskilled labourers. Plumbing services and electrical wires can also be included within the wall systems.



Figure 56: Moladi mould system on a building site (Engineering For Change | By Engineers, For Everyone, 2020).

g. RePlast blocks:

RePlast blocks are produced by utilizing the ByFusion systems of heating and compressing recycled plastics. ByFusion is a company that develops machines that convert plastic waste to RePlast blocks. These blocks are to be employed as wall fill or infrastructure work. The device itself is portable enough to be transported in one shipping container to the location of the plastic waste. This system has not been applied in a large real-life working scale because it is still in the prototyping phase. The blocks are made by the following process:

- Recycled plastic is put in the RePlast machine.
- RePlast machine shreds the plastic into tiny fragments.
- The plastic pieces flow through a water boiler and compacter, which compresses them into the RePlast blocks. No adhesives are used in this process, and it is non-toxic.
- The RePlast machine also recycles wastewater for about 10-16 weeks using a 600-gallon water tank.

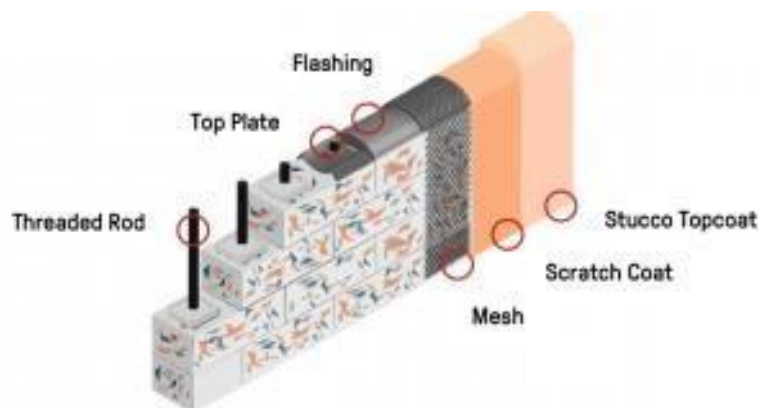


Figure 57: RePlast block construction (Engineering For Change | By Engineers, For Everyone, 2020).

The RePlast wall structure is also used in conjunction with rebar steel rods going through the blocks. The bricks have two holes; therefore, two steel rods are needed through each brick. The layers are made up of the RePlast blocks, a chicken wire mesh to cover the block surface, a scratch coat layer and a stucco topcoat. A steel plate is on top and flashing before the chicken wire and other coatings. This is shown in the diagram below.



Figure 58: RePlast blocks

6.2 Comparison

The bottle bricks are straightforward to make; however, an additional adhesive substance (adobe, cement, sand, e.t.c) is needed to hold the bricks together. The Bloqueplas method may be a good solution, especially if there is a large quantity of free or cheap plastic waste available. However, it requires highly skilled engineers for construction as well as a high start-up investment. The Ifrique floor tiles are a good solution, especially as it involves low-cost materials and no machinery. However, there is room for improvement as it is not standardized at all. The Mod roof system requires too many manufacturing steps for feasibility for a low-cost venture. The pretty plastic works well, especially as it is fire resistant. However, it also needs a high start-up investment cost, and the material is not structural; it only functions as a cladding system. The Moladi building method is quick and easily adapted by unskilled workers. However, it is relatively expensive because of the use of cement in construction. The RePlast process is demountable, and all waste plastics can be used in production. However, it involves many production steps and additional materials such as metal and plaster are required.

Table 5 below shows a summary comparison of the different precedents. The strong aspects of each precedent can serve as a source of inspiration for the future design of building component.

Plastic waste method	Positive	Negative
Bottle bricks	Simple to manufacture Quick production	Additional concrete required. Thermal insulation is dependent on filling material
Bloqueplas	Reuse of plastic Quick production Easy to build	High wall thickness Many production steps Additional material required

Ifrique Collections and Designs floor tiles by Intissar Bashir Kurfi	No machinery used Quick production Mould is used multiple times	Additional sand required Not standardized process Very harmful fumes
Mod roof	Waste material Reuse of plastic Insulating capacity	Beam system required. The coating requires new plastic Many manufacturing steps Only applicable to roof
Pretty plastic	Reuse of plastic Waste material Fire resistant	Only applicable as cladding High tech production
Moladi	Thermal mass Insulating cavity Quick production	Use of concrete (cement) High-tech production of the moulds Waste production
RePlast	Transportable production line Insulating All waste plastics can be used Demountable	Additional material required Many production steps High wall thickness

Table 7: Precedents comparison

6.3 Plastic reuse initiatives in Nigeria

There are a few other precedents for plastic reuse within Nigeria, even within the IDP camps.

i. Changa Datti

One of the initiatives for plastic reuse within Abuja is a social enterprise called Changa Datti. The word ‘Changa Datti’ derived from the local language Hausa can be directly translated as ‘to change or transform dirt’. The name represents the fact that the company was established and is based in northern Nigeria, as the primary language of communication in the region is Hausa.

The enterprise deals with collecting waste plastic, especially pure water sachets and PET bottles, and other recyclable materials like papers, aluminium cans, cartons, cardboard, glass, and so much more. These raw materials are transformed into bales or flakes and are then sold to recyclers or manufacturers who need them to produce other goods. This whole process complies with the relevant Sustainable development goals set by the Nigerian government and sensitization campaigns across religious institutions, local communities and educational institutions. The main focus is the 3 R’s of sustainability: Reduce, Reuse, Recycle.

Chanja Datti’s business operations span from the collection of post-industrial and post-consumer recyclables to sorting according to grade and type, cleansing and preparation, crushing into flakes or baling, and sale of the flakes/bales to other manufacturers or re-users. They run various campaigns such as Recycling for IDP initiative, where IDPs are supported by people who donate recyclables such as PET bottles, beverage cans, old newspapers, glass bottles, corrugated cardboard, old textbooks, cartons e.t.c. Or Bottlesforbooks Initiative, where people can donate bottles in exchange for money. This shows that there is already some sensitization around plastic reuse.



Figure 59: Changa Datti logo (<http://www.chanjadatti.com/>).

ii. Planet 3R

Planet 3R is another social enterprise committed to converting plastic and textile waste into eco-friendly end products using the traditional weaving technique. This process implements the 3R's of sustainability (Reduce, Reuse, Recycle). They recognize that a serious problem in Nigeria is plastic waste, especially from water sachets and nylon bags, so they collect them, shred them and weave them into useable products. They are also used in conjunction with old clothes or old materials to make products such as bags, fashion wears and home décor.



Figure 60: Shoes and bags made from recycled plastic (<https://planet3r.org/>)



Figure 61: Shoes and bags made from recycled plastic (<https://planet3r.org/>)

7

Design Brief



7.1 Introduction

This is the design brief for a low-cost building component made out of waste plastic (and possibly other material) that improves the living conditions in the IDP settlements of Abuja, Nigeria.

The 'building component' is defined as any module which can be used repetitively as a building material, functioning as either a structural material or cladding material. It should be able to protect the inhabitants of the IDP camp against the weather elements.

The context is defined as Kuchingoro IDP camp within The Federal Capital Territory, Abuja. This settlement is used as a starting point for the design. However, the solution can be applied to any IDP camp across the country.

7.11 Production method requirements:

The production of the building component should be feasible within the IDP camp, meaning:

- The investment for the production line should be as low-cost as possible to enable charities, the government, local entrepreneurs and other organizations to invest easily.
- The production should also be as low tech as possible. The construction process should be easily teachable to the people within the camp, so they become self-subsistent.

7.12 Building method requirements:

The building method should also be feasible within the IDP camp, meaning:

- It should be easily identifiable with the existing housing methodology within the local region.
- It should be an incremental building component. The households within these camps do not make much money; therefore, they should be able to be expanded easily.
- It should be demountable. If the residents want to return to their original place of origin, the components should be easily removable and transportable.

7.13 Material requirements:

The material used to produce this building component should be plastic made from LDPE, HDPE and or PET. This will be collected locally, but it may be inconsistent in quality as they will be collected from different points.

7.2 Brief requirements

- i. Durability (>5years)

The building component should be applicable outside; thus, it should be water-resistant and watertight. Seeing as this is to be located in a tropical region, it should be as UV resistant as possible. The majority of the IDPs reside in the camps in Abuja for at least two years; therefore, it should be sturdy enough to last for a long time if required.

ii. Insulation

The minimum average Rc-value of the wall component should be around 0.20 m²K/W (comparable to that of a compressed brick wall).

iii. Cost:

Although the camp residents are very low-income earners, research has shown that they receive income regularly from residents within Abuja. Therefore, the cost of building the entire bacha should not exceed NGN 30,000 (EUR 65.52).

iv. Size:

Each building component should be able to be carried and stacked repeatedly by at least two people. Therefore, each element should not exceed 25kg per square metre. The wall thickness should be kept to a minimum, preferably under 200mm, in order to maximize the space within each room. It should also be able to have a total height of at least 2.4 metres (UNHCR guide 2m) to accommodate a doorway of 1.8 metres. The area should be at least 20m² for an average of 5.5 families and a minimum of 3.5 square metres per person.

v. Fire safety:

The building component should not be easily combustible. It should be able to withstand surface temperatures of at least 70 degrees Celsius to enable the residents to escape quickly and easily.

vi. Stiffness

The building component stiffness or rigidity needs to be comparable to that of the polyethylene sheets that the camp members use now, and it should be as still as the zinc panel they prefer.

8

Material Design



8.1 – Introduction

The design brief has been derived based on the literature research and the site analysis. The subsequent stage involves applying the design parameters to a façade product that can be used in real life. There are three steps involved in this, namely:

- Selection of a design material: This will include a comparison between the most prevalent plastics within Abuja and a selection based on functional and realization aspects. This will help understand the fundamental properties of the material chosen and the processing properties of the selected plastic.
- Prototyping: Based on the properties of the chosen material, different prototypes will be developed and tested. Various methods of creating the building component will be explored; it is a learning by doing approach; therefore, each prototype serves as a way to learn what is suitable for the building component within the limitations of the design brief.
- Application in practice: Based on the results of the prototype, the system used for physical testing of the final prototypes is presented.

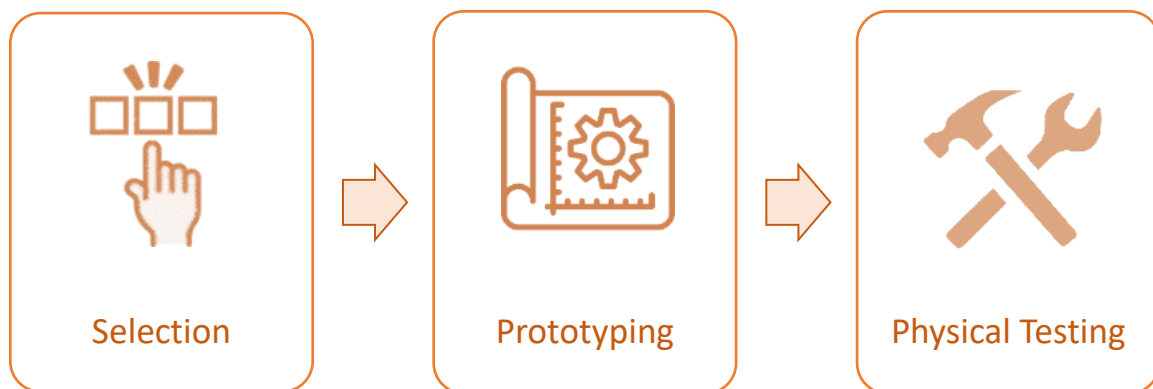


Figure 62: Material design process

8.2 Choosing the plastic.



Figure 63: Phase one of material design

According to the literature research, there are two significant sources of plastic waste in Nigeria and Abuja. The HDPE plastic bags, LDPE water sachets, and PET bottles. In order to choose the plastic, which is most suitable, the Kesselring method of comparison will be employed. This method is intended to assist designers in decision making especially when there are multiple factors involved. Human beings process information within a limited capacity; therefore, each criterion will be evaluated separately. Once this is done, the values calculated must be combined into a score for each alternative's "overall" value. Kesselring created a visualization method that allows multiple variants to be compared to one another.

The Kesselring method involves the separation of the required criteria into functionality and realization. Each criteria group is assessed, and a total value is derived. The total scores of the realization and functional group are expressed as a percentage of the maximum score. The diagram shows the criteria for realization on the x-axis and the percentage criteria for functionality on the y axis. The most suitable variants have high scores and are closest to the diagonal line drawn from the origin point.

Furthermore, a selection area should be limited by dividing the area into two with a minimum border set by the x and y value of 60 and by (x + y)-value of 55%. The major benefit of the Kesselring method, which is unachievable in bar diagrams or other tables, is that the singularities are visualized. It allows one to see whether functional or realization improvements are required.

First of all, the material properties of LDPE, HDPE and PET are compared.

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	Higly flammable	Highly flammable
Fracture Toughness MPA.m ^{0.5}	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 8: Material properties comparison between LDPE, HDPE and PET (CES EduPack, 2019)

This table shows that LDPE is a less efficient version of HDPE; therefore, HDPE and PET are used for the Kesselring comparison. The functional properties have to do with material properties, and it is ranged on a scale of 1-5, 1 being the worst and 5 being the best. This has been considered with regards to the tropical nature of the context. For example, a lower thermal conductivity is favoured because it is a tropical country. The realization properties have to do with the reality of building it within the context. For example, the availability of machines to reprocess the plastic is essential. The type of plastic favouring less manipulation with water or machines will be favoured due to the low-income nature of the context.

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 9: Functional aspect comparison between HDPE and PET

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 10: Realization aspect comparison between HDPE and PET

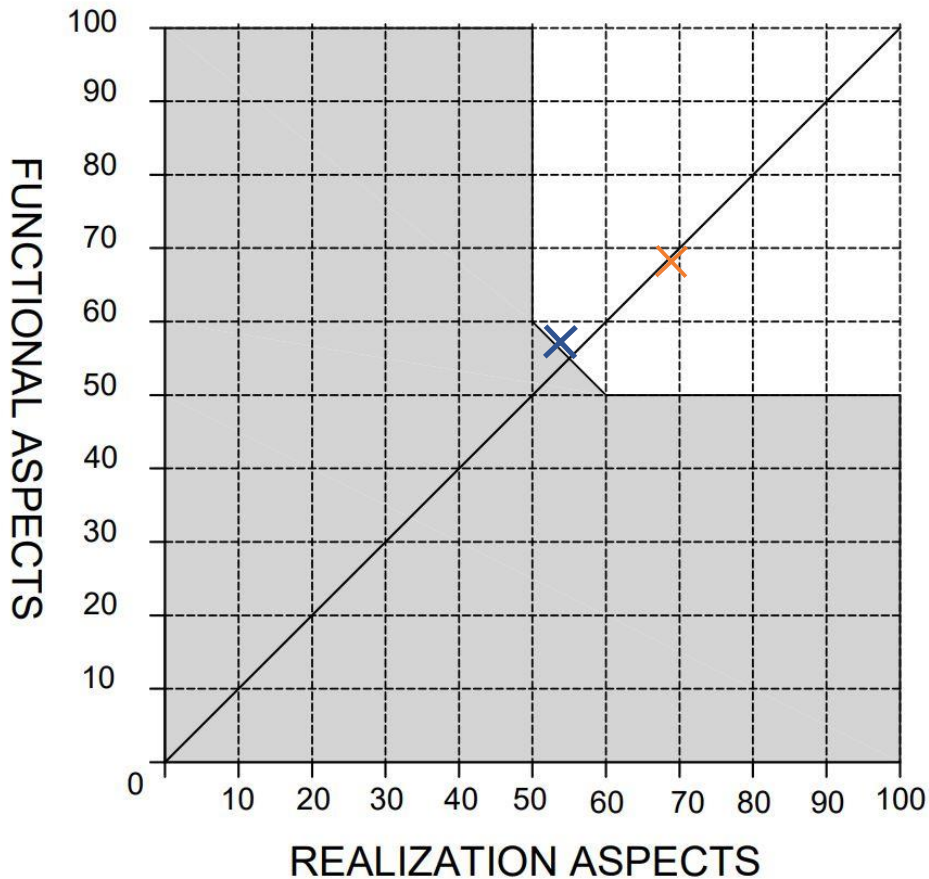


Figure 64: Graphical representation of the functional and realisation of HDPE and PET

The results show that an HDPE component will be more suited if the functional requirements are more critical than the realization requirements. However, the PET is closer to the line; therefore, there is a balance of functional and realization aspects. Both of which are important for the production of the building component. PET is chosen as the building material for this project.

8.3 PET characteristics

i. Overview

PET was initially used only to produce polyester, that is, fibres for clothing. Over the last thirty years, it is now used for blow-moulded food containers and drinks. Its generally good properties and superiority to glass for those specific uses (especially strength to weight ratio and brittleness) have become very important in recent years.

ii. Strengths

It is easily gotten, has a good melt flow and surface finish, it has high stiffness and strength as an engineering thermoplastic. It is a good water barrier; it has excellent transparency, but it can be easily coloured. It also has practical and established recycling methods.

iii. UV durability

As this is to be applied in a tropical region, it is essential to understand the UV durability constraints. Generally, UV radiation in the 290-400 nm range can possibly affect materials exposed to it. UV degradation is usually measured in terms of mechanical property loss. PET has poor UV radiation durability, meaning that PET needs to be protected if it is to be exposed to UV radiation. It can be suitable for a few weeks – months, but the material will degrade under direct sunlight. Various studies have been carried out within recent years to determine the extent of degradation and the correlation to mechanical properties.

In a study carried out by Aljoumaa, K., & Abboudi, Semi-crystalline polyethylene terephthalate (PET) was aged 670 days under direct sunlight exposures with varying temperatures laboratory conditions. The inner surface did not experience any chemical degradation, and all the observed changes were only to the physical nature of the PET. Exposure to sunlight leads to an increase in crystallinity, decreased tensile stress and an increase in hardness. After 670 days, the tensile stress decreased from 167.9MPa to 150.6 and 133.8 MPa for samples aged under sunlight and those aged in the dark, respectively. The strain also reduced by 12% and 23.8%, respectively. These results show that sunlight is a factor in PET stability.

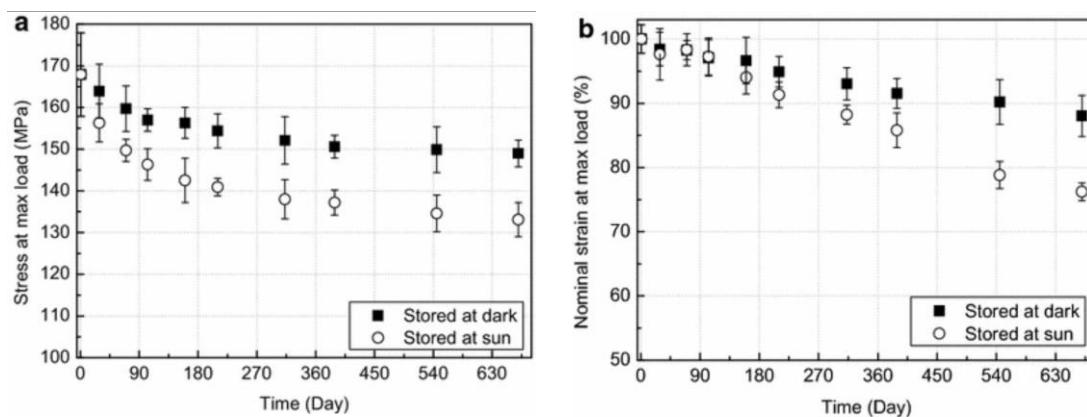


Figure 66: Stress at max load (a) and normalized nominal strain (b) for aged PET samples, filled square at dark, open circle under direct sunlight (Aljoumaa, K., & Abboudi, M.,2015)

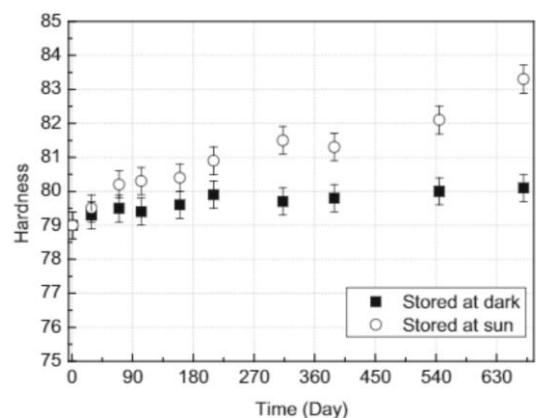


Figure 65: Hardness of PET samples as a function of ageing time, filled square indoor storage, open circle outdoor storage under direct sunlight (Aljoumaa, K., & Abboudi, M.,2015)

Furthermore, the degree of crystallization also affects UV durability. 'Crystalline' in this case implies that the polymer chains are closely packed and parallel to one another, while 'amorphous' indicates that the polymer chains are disarranged. So, the more opaque the PET is, the more crystalline it is. Crystallinity can be caused by

heating the plastic above the glass transition temperature (T_g) and is frequently accompanied by molecular orientation. The glass transition temperature (T_g) of PET is high at 70°C .

In another study carried out by Chaisupakitsin, Chairat-utai, & Jarusiripot. In this study, researchers left three types of soft drinks filled in Polyethylene terephthalate (PET) bottles, carbonated water in green, pink bottles and drinking water in a clear bottle on the rooftop of a building for eight months. After extended exposure to sunlight, the shape of the bottles remained the same, but the plastics tensile strength reduced. The maximum tensile forces of the green and pink PET bottles are much higher than the clear PET bottles before the experiment. The maximum tensile force is directly proportional to the level of polymer crystallinity. The higher the degree of crystallinity, the stronger the plastic; thus, the pink and green bottles have a higher tensile strength than the clear PET bottle. However, all the bottles indicated a slight reduction in maximum tensile forces after exposure to sunlight for eight months.

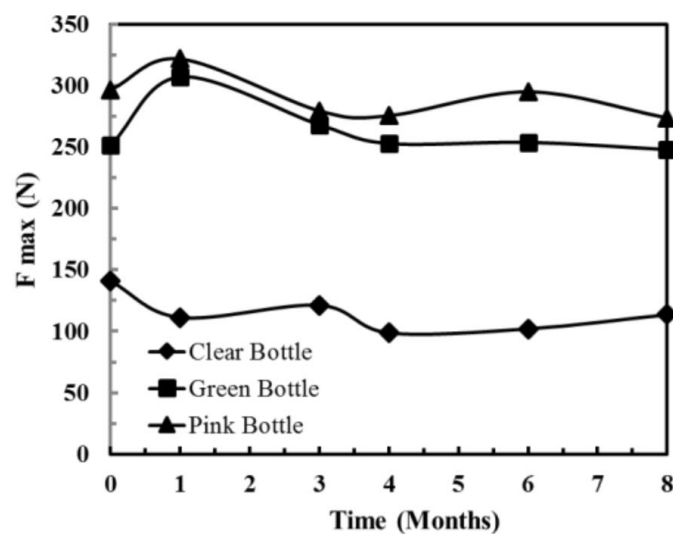


Figure 67: Maximum tensile force (kN) of PET bottles at various exposure time (Chaisupakitsin, M., Chairat-utai, P., & Jarusiripot, C., 2019).

iv. Limitations

PET may be problematic with injection moulding; it is susceptible to heat degradation but in amorphous form. This is less so when it is semi-crystallized. It burns easily, but a fire retardant can be used to prevent that. During processing, harmful fumes may be released, especially at very high temperatures, and it has a high mould shrinkage.

8.4 Prototypes

Prototyping

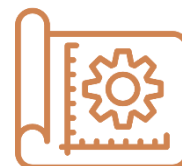


Figure 68: Phase two of material design

Once the material is chosen, the next step is to determine what kind of building component will be produced. The initial intention at the beginning of this research was to produce interlocking plastic bricks suitable for a system that will not involve extra materials. Upon further research, the processes used to create such bricks

like the bloque plas or the RePlast blocks are the injection moulding method which is highly expensive and require a factory set up. The more compacted an object needs to be, the more complicated and expensive the process is. Furthermore, interlocking systems require intricate connections; these are difficult to separate from a mould successfully.

Additionally, the camp residents are content with the wooden framework system and would prefer a stiffer material than the Polyethylene sheets, which they use now. The building component has to be designed with the end-user in mind; therefore, the major conclusion is that a system with flat and wide sheets made from PET is more suitable for a low-cost technological application.

The material currently used in the camp is PP (polypropylene) fabric. PET is rigid when heat is applied to it; thus, the idea of a woven sheet in which heat is applied to increase rigidity came about. Different prototypes have to be developed to test the temperature at which the woven material would be suitable and a weaving technique. The application of heat will also increase the opacity and make it more crystalline and rigid.

PET slicer

Weaving requires thread; therefore, the first step is to convert the PET bottles to thread. This is done using a PET bottle slicer which was built manually. The slicer is made of wood with a groove as thick as the thread thickness and a blade. The plastic bottle is cut at the bottom and placed at the top of the PET slicer. The bottle edge is pressed until it passes through the groove to produce the first end of the thread. The piece is then pulled continuously; this causes the bottle to rotate while long strands come out of the end of the PET slicer.

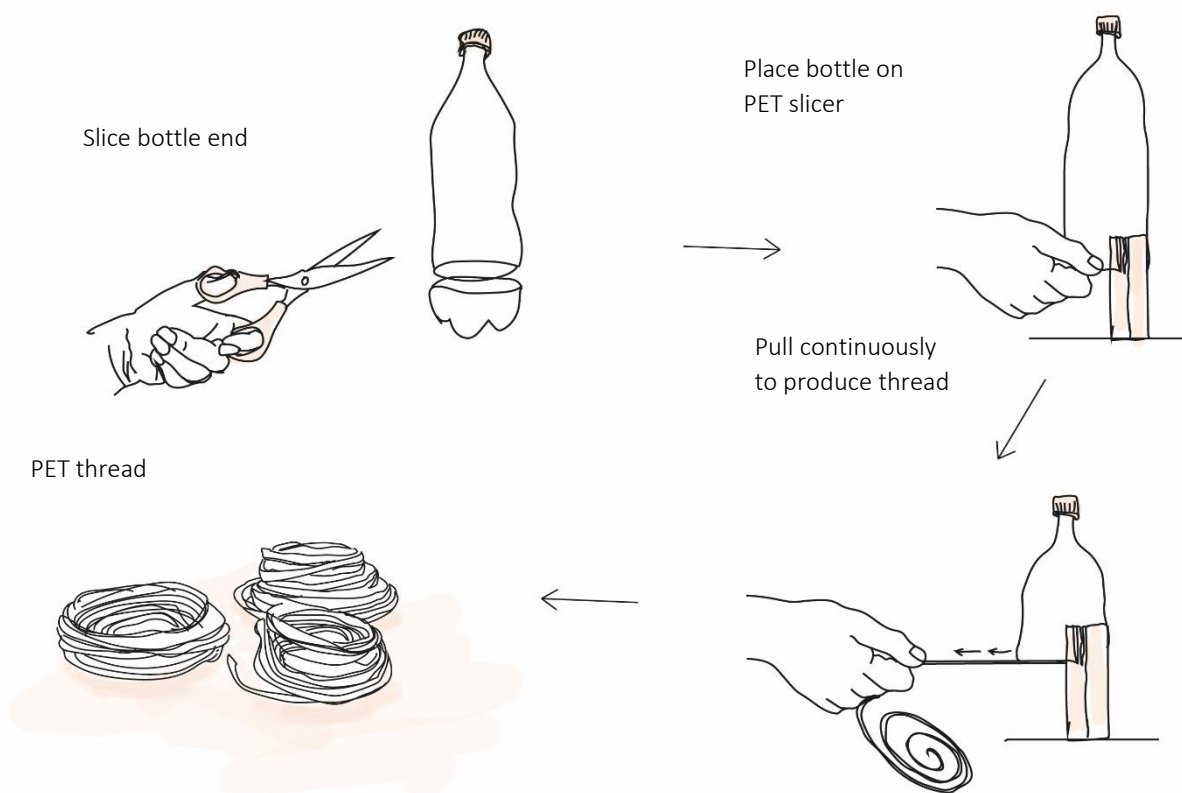


Figure 69: Schematic diagram of PET thread process

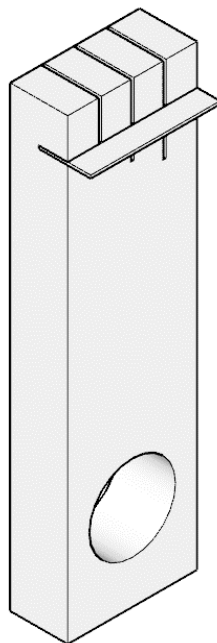
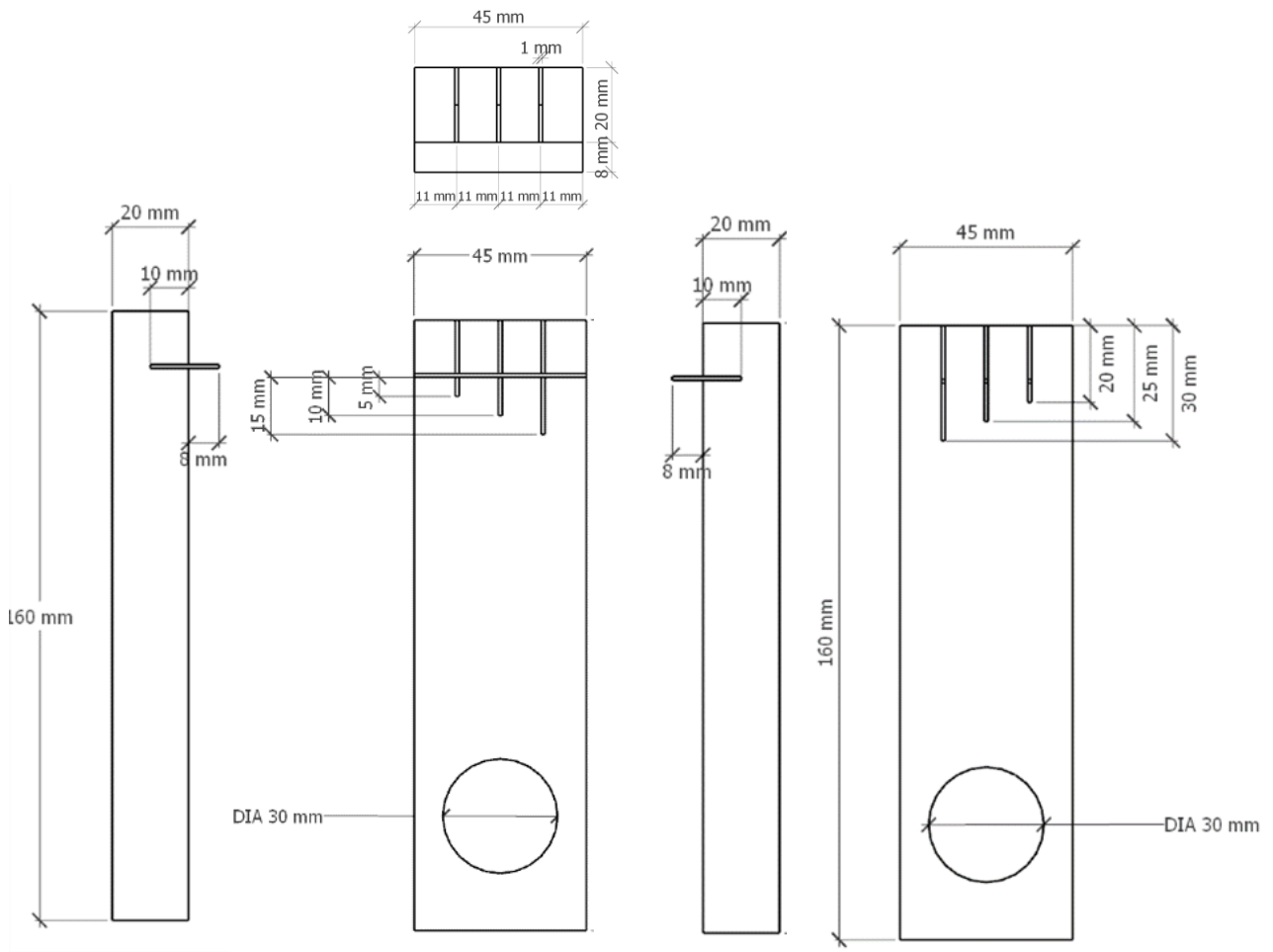


Figure 70: PET slicer detail drawings

The PET slicer is made with a simple blade and a wooden block. A hole is added in order to utilize a g-clamp for stability. The first attempt at slicing the thread was not very successful as the PET kept cutting. Therefore, the design was modified to include a stick attached to the PET slicer to ease the control of the bottle. This ensured that the sting was continuous and easily guided. The resulting thread of 10mm is chosen for the weaving because it is the easiest to manipulate.



Figure 74: First PET slicer model with 20, 25 and 30mm space for thread



Figure 73: PET slicer with a pole attached for ease of slicing

An additional PET slicer for only 10mm was made as a second prototype. This version included nails on either side of the blade to ensure that it does not move during the slicing process.

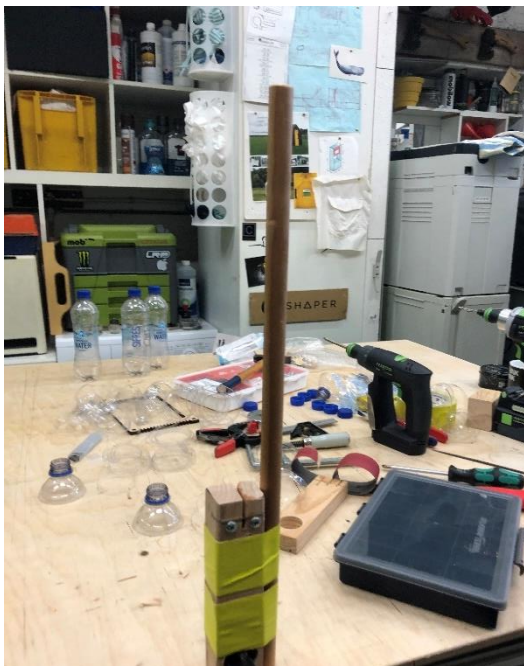


Figure 71: Final PET slicer for 10mm thread



Figure 72: 10mm thread

Looms:

A makeshift loom was also constructed to aid the weaving process. This is made out of wood, and nails are used as the turning point for the thread.

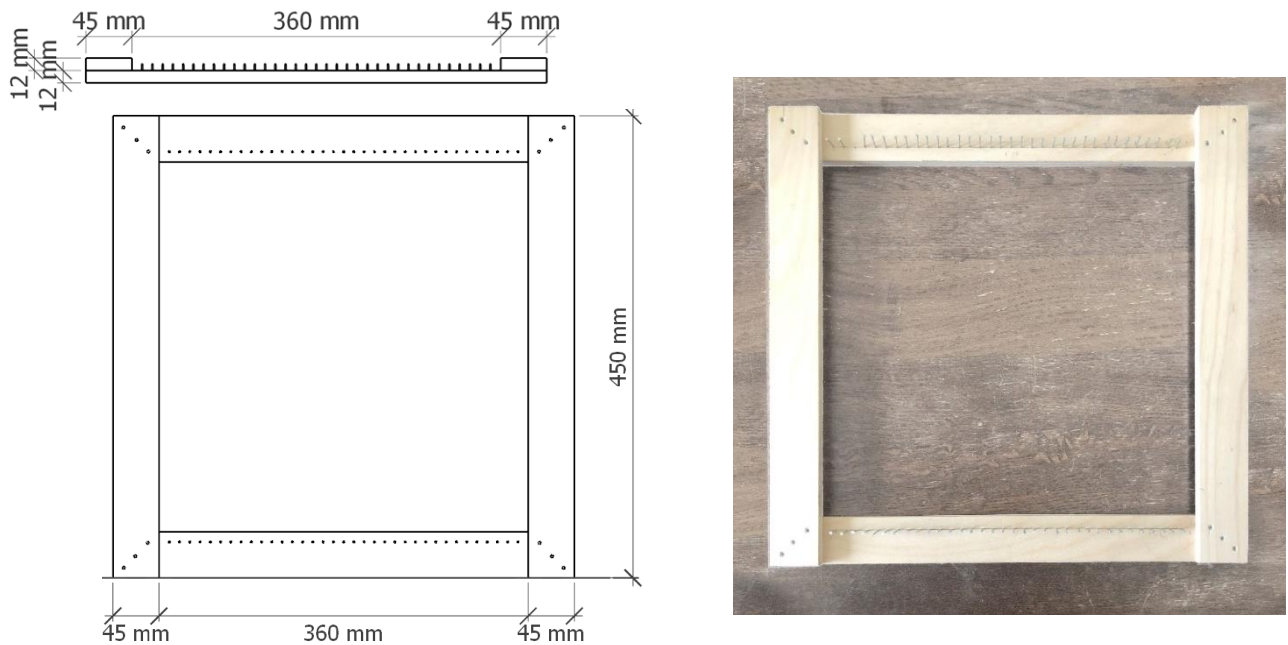


Figure 75: Makeshift loom made from wood and nails

A smaller beginners loom was also gotten for the creation of smaller prototypes. This was pre-made specifically for beginner weaving.

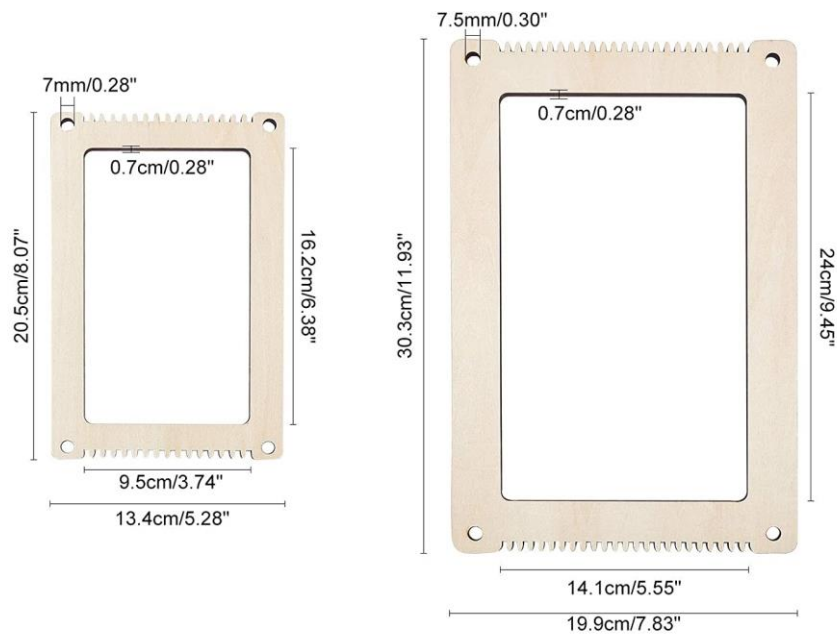
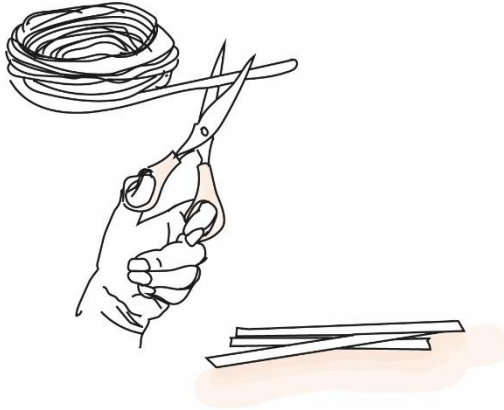
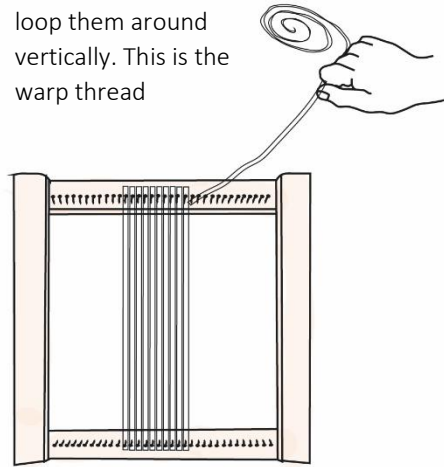


Figure 76: Beginners loom. (https://www.amazon.nl/gp/product/B08M9442Q3/ref=ppx_yo_dt_b_asin_title_o02_s00?ie=UTF8&psc=1)

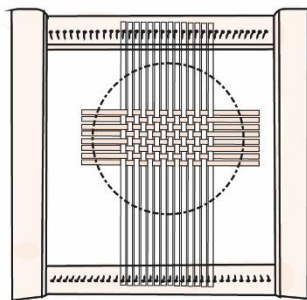
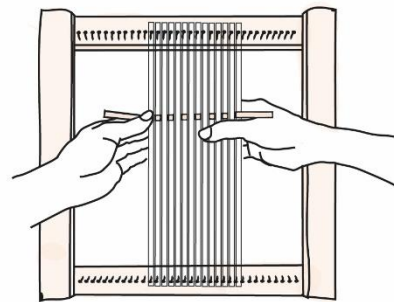
Slice PET thread into strips



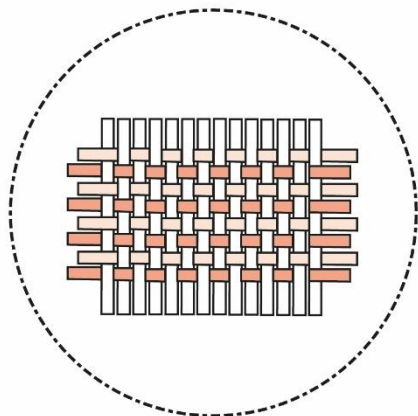
Attach the strips to the pins in the loom or loop them around vertically. This is the warp thread



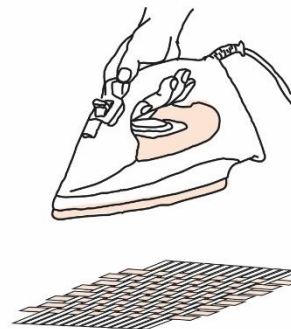
Start weaving it by passing the thread horizontally, these are the weft threads



The weft threads are passed over and under each warp thread, with each row alternating



This weave technique is called the plain or tabby weave



Iron the PET to make it stiff

Figure 77: Schematic of PET weaving process

Prototype a

For the first plastic prototype, the PET string is woven with a simple weave technique called the plain weave is used. It is observed that the application of heat from an iron does not make the threads stick together. They contract but do not melt. This is understandable as the melting point of PET is very high, about 250 degrees Celsius, and the iron is not up to that temperature. A soldering iron is used to melt the joint pieces together. The soldering iron reached a very high temperature, the plastic strip pieces melted together at the points of contact to one solid piece.

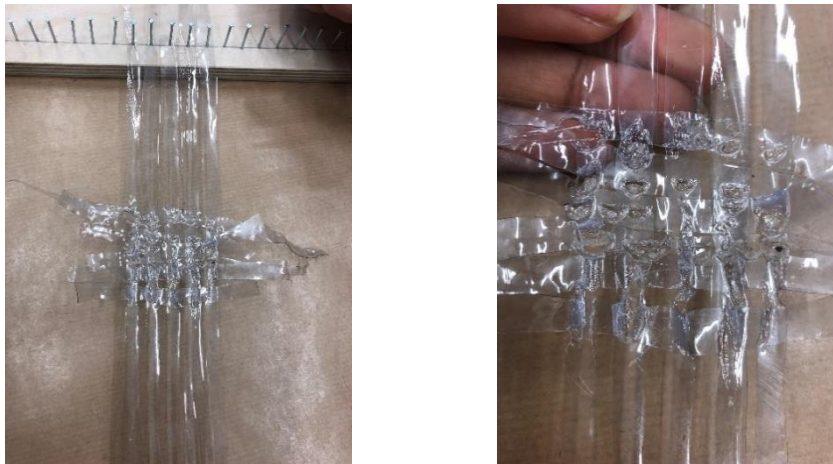


Figure 78: First plastic weaving prototype

Prototype b

The next prototype is made on the premade loom. As it is a small loom, a smaller thread of 5mm is used with the same plain weave pattern. The material visibly contracts and becomes more rigid when heat is applied to it with an iron. However, it does not melt enough to join together. The weave does become much tighter and stiffer.



Figure 79: Weaving prototype using small loom

The plastic is then subjected to a higher temperature by placing it on an iron base and using an unplugged iron to maintain the pressure and flat shape of the plastic. A baking paper is used on one side on top of the plastic

piece for easy removal. The plastic contracted further, and a part of the PET crystallized and became more opaque, as shown in the images below.



Figure 80: Heat test with iron and metal base

Prototype c

The next prototype involved the same weaving method, but baking paper was placed on both sides, and the iron was switched on to ensure heat distribution on both sides. The results show that the baking paper over the metal got burnt when the plastic melting point was reached; thus, that end broke off. Furthermore, the heat distribution was uneven, so one part was more crystalline than the other.



Figure 81: Heat test with baking paper, iron and metal base

Prototype d

For the next prototype, I attempted to join two separate pieces together. Two different woven parts are heated together on different axes and are put over the metal as done in test b. The results show that even though both pieces contract as expected, they do not join together.



Figure 82: Prototype with two separate pieces

Prototype e

This prototype involves using plastic in conjunction with twine. The plastic causes the string to contract but seeing as the melting point of the rope is different, it begins to burn while the plastic hardens. This disparity is not suitable; therefore, the twine will not be used for future prototyping.



Figure 83: Prototype with PET thread and twine

Prototype f:

The next set of tests are done to determine how to even out the temperature distribution and determine what temperature is suitable to join the plastic pieces together. A cast-iron skillet and a steel inductor adapter are used to even out the heat distribution in further heat testing. The inductor distributes the heat evenly, and the cast iron is heavy, thus maintaining the plastic's pressure while also heating up. An infrared thermometer is also used to measure the temperature of the different plastic. Two different plastic strips are used for this test. Different temperatures of the iron skillet are measured after the heat is applied to the plastic pieces.



Figure 84: Material used for heat testing prototype f. A cast-iron skillet, an induction pan and infrared thermometer





Figure 85: Testing the prototypes and measuring the temperature of the metal press

These results show that a temperature of around 125°C to below 200°C the plastic to contract. 200°C is suitable enough for the plastic pieces to contract but also bond together. 250°C completely melts the plastic. It is important to note that it is still difficult to control the temperature.

Prototype g

To be sure that this theory holds for a larger piece, another prototype with the plain weaving pattern like test b is used. The results show that the plastic contracts and bonds together at 210 degrees; however, the weaving pattern does not stay flat.



Figure 86: Prototype g before and after heat testing

Prototype h

The weaving pattern may affect the integrity of the prototype; therefore, a different weave type is explored. In this type of weaving, long strips are created by interlocking the bottle pieces in a zig-zag fashion; the process is shown in the diagrams below. In this case, the connection is stiffer, and a larger area is made with fewer pieces.

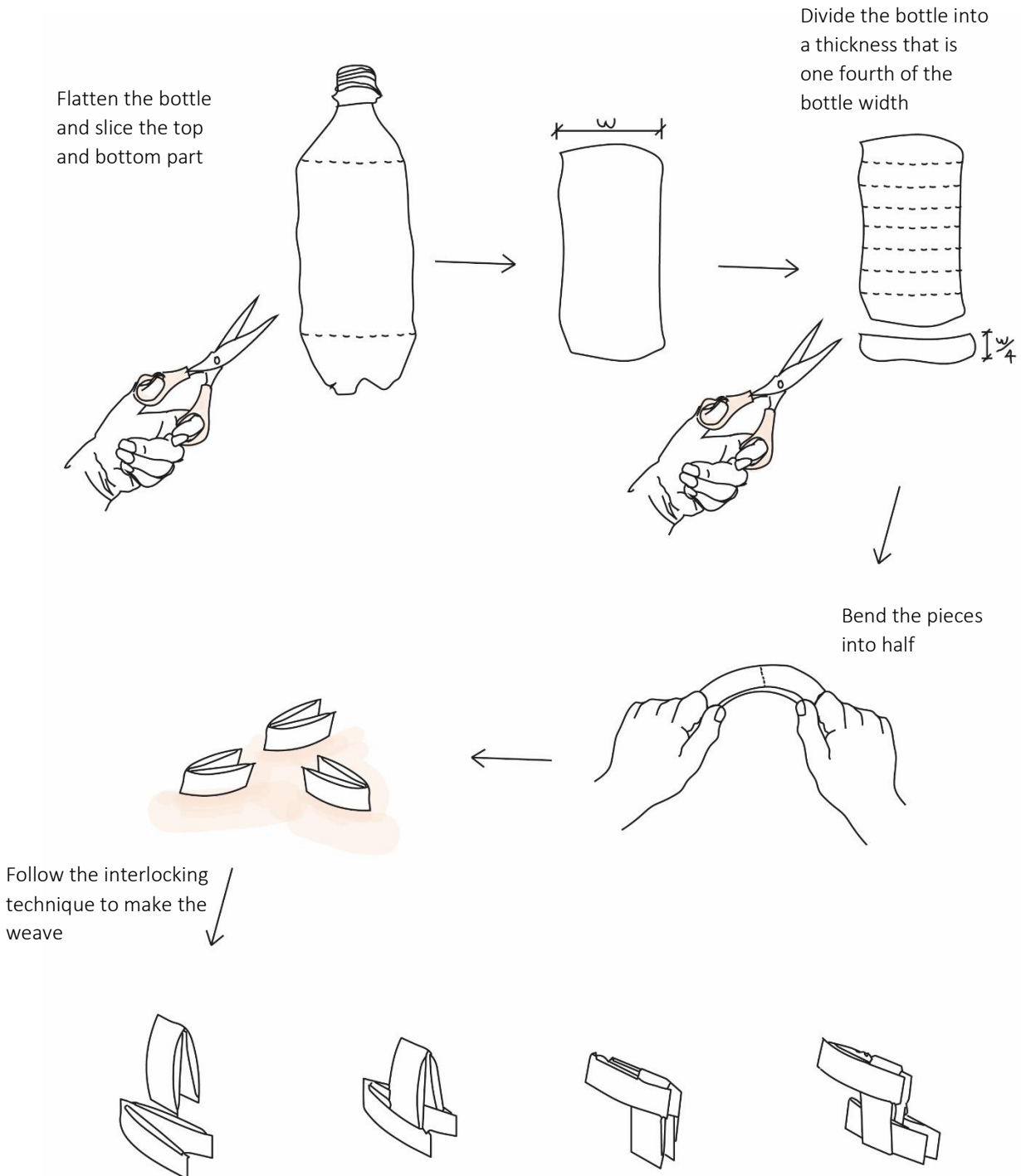


Figure 87: Schematic zig-zag weaving diagram

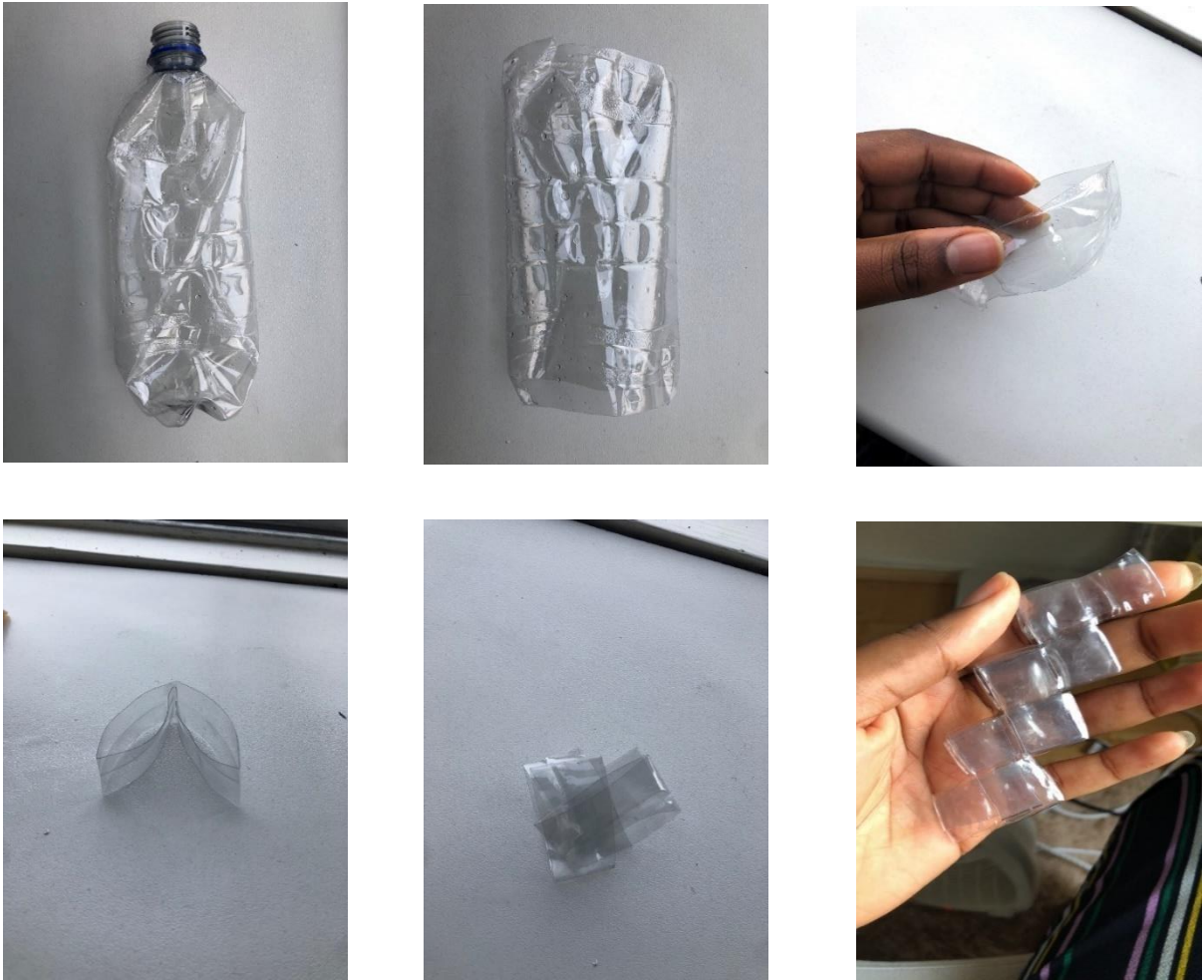


Figure 88: Zig-zag PET weaving process.

With this prototype, the bottle is folded; therefore, it is thicker. The connection is also more substantial; therefore, one woven layer should be suitable enough. However, the stiffness can be improved upon without necessarily melting the plastic. In this case, an iron can make the connection stiffer and the material more rigid.



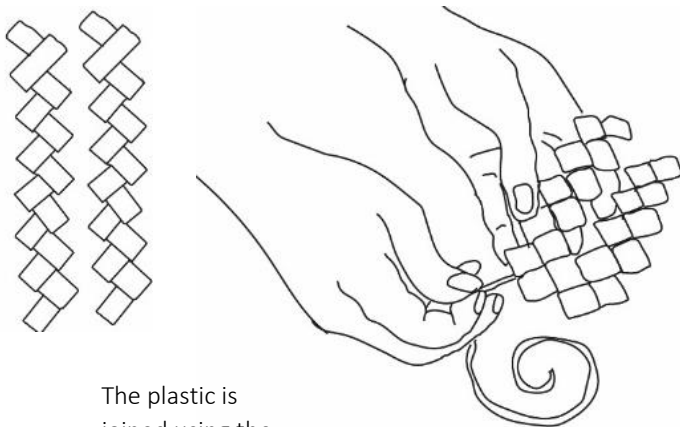
Figure 89: Heat application and infrared thermometer measurement

The temperature of the iron is around 173-175 degree Celsius. This is above the glass transition temperature of PET; thus, crystallization begins, but it is below the melting point of PET, so the PET stays solid. The crystallization decreases the material's opacity, makes the weave tighter, and causes all the material to contract. With the heat of around 240 degrees Celsius, the plastic begins to crystallize and harden further; however, holes start to form in the plastic, it is also more breakable. This scenario is not suitable as the integrity of the material is affected; therefore, an iron alone will be used to apply heat.



Figure 90: Heat testing above glass transition temperature and measurement with infrared thermometer

The next step is to figure out how to extend the weave pieces in both the x and y-direction. It is possible to connect them with the PET threads made earlier; however, it may affect the water tightness of the overall material, as shown in the diagram below.



The plastic is joined using the thread from the PET slicer

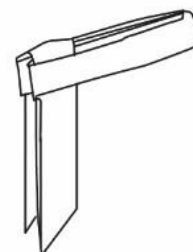
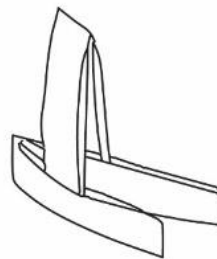
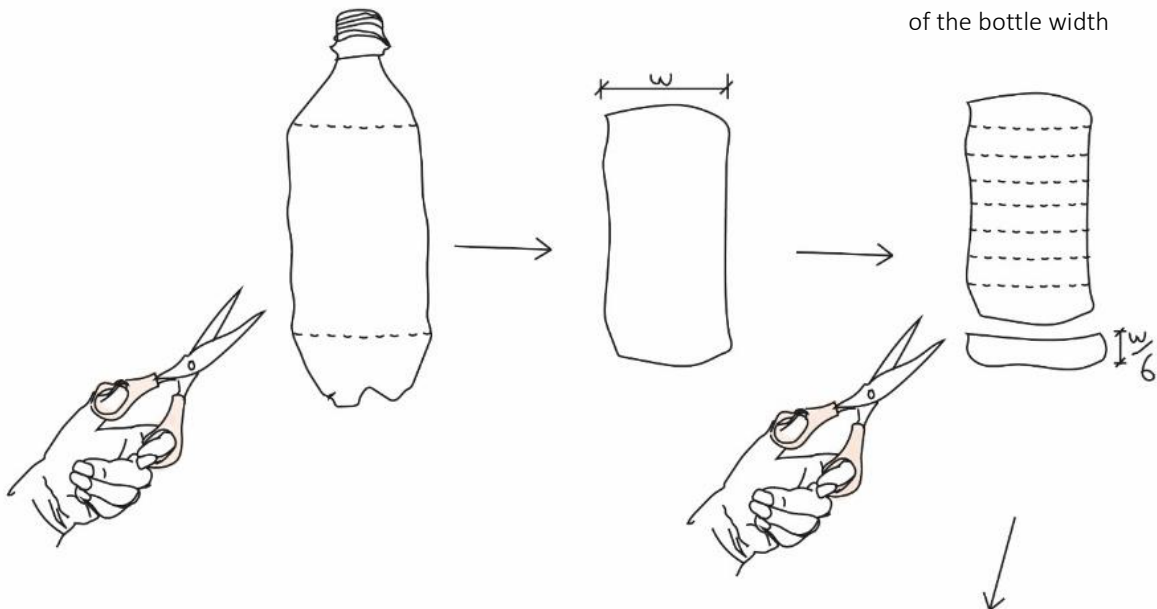


Figure 91: Joining the zig-zag pieces with PET thread

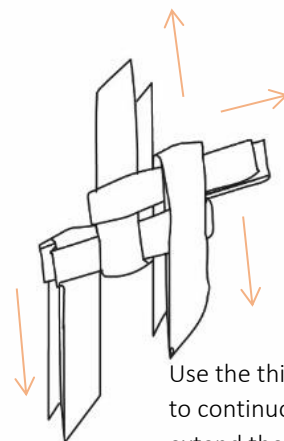
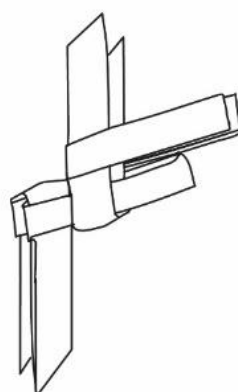
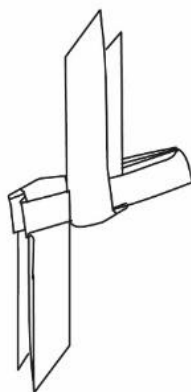
Prototype i

A further step would be to weave the plastic continuously to avoid unnecessary seams which arise when separate long strips are joined together. In this case, the strip thickness is one-sixth of the bottle width to allow for an extension of the plastic. PET thread can be used to tighten the hold of the plastic further.

Divide the bottle into a thickness that is one sixth of the bottle width



Follow the interlocking technique to make the weave.



Use the third piece to continuously extend the weave in all directions

Figure 92: Schematic process of continuous zig-zag PET weaving

This piece is continuous and becomes quite stiff and opaque once heat is applied to the surface. PET thread can also be used further to strengthen the tightness of the weave before heating.



Figure 93: Continuous zig-zag woven prototype

8.5 Physical testing

Physical testing



The material properties of PET were described earlier in chapter 8 and how they can influence the building component performance. In this chapter, there will be a comparison between different prototypes regarding the material's tensile strength. Tensile strength testing is a standard mechanical test done for different materials. The test results for this type often give a large amount of information regarding the material tested. In this test, a normal force is applied to a specimen unidirectionally, and the resistance of the material to the force or stress rate is measured. The set-up is shown in the diagram below.

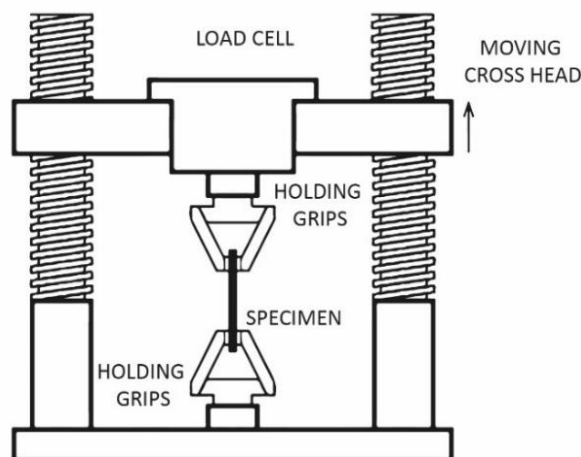


Figure 94: Tensile strength test set up. Source: Nguyen (2012)

The result of this test is a stress-strain curve. The curve is essential in understanding the behaviour of a specimen under loading conditions. A typical stress-strain curve for elastic ductile materials is shown below. Important material properties can be derived from this curve.

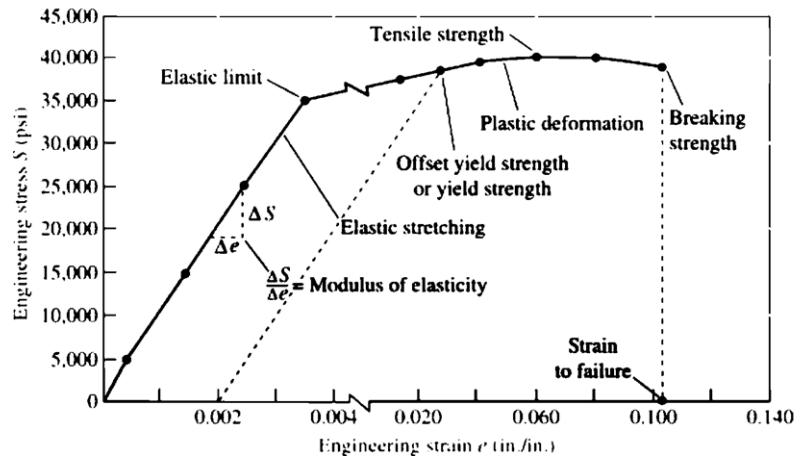


Figure 95: A common stress-strain curve (Askerland, 1988).

There are six prototypes tested altogether, as shown in the table below. All prototypes were between 40-50mm wide and 15-20mm long to enable testing on the machine.

Sample number	Type	Thickness
A1	Polypropylene Cement bag (two layers)	0.1016mm
A2	Polypropylene Cement bag (four layers)	0.2032mm
B1	Small woven PET plastic bottles sliced at ends (9 bottles)	6-8mm
B2	Small woven PET plastic bottles with PET thread (8 bottles)	6-8mm
B3	Big woven PET plastic bottles with PET thread (five big bottles)	8-10mm
B4	Big woven PET plastic bottles with PET thread (five big bottles)	8-10mm

Table 11: Test samples and properties

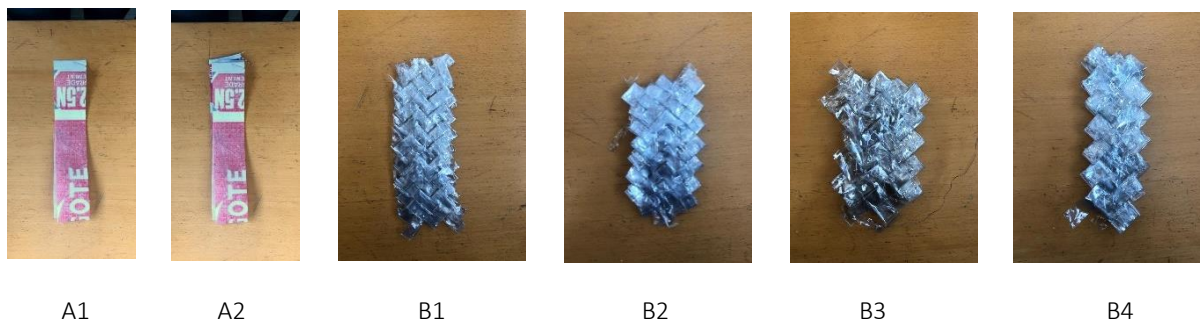


Figure 96: Prototypes for physical testing

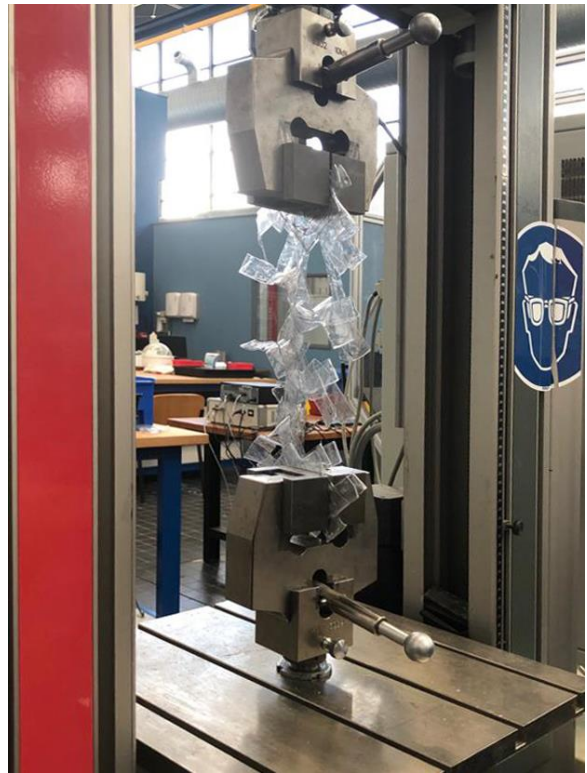
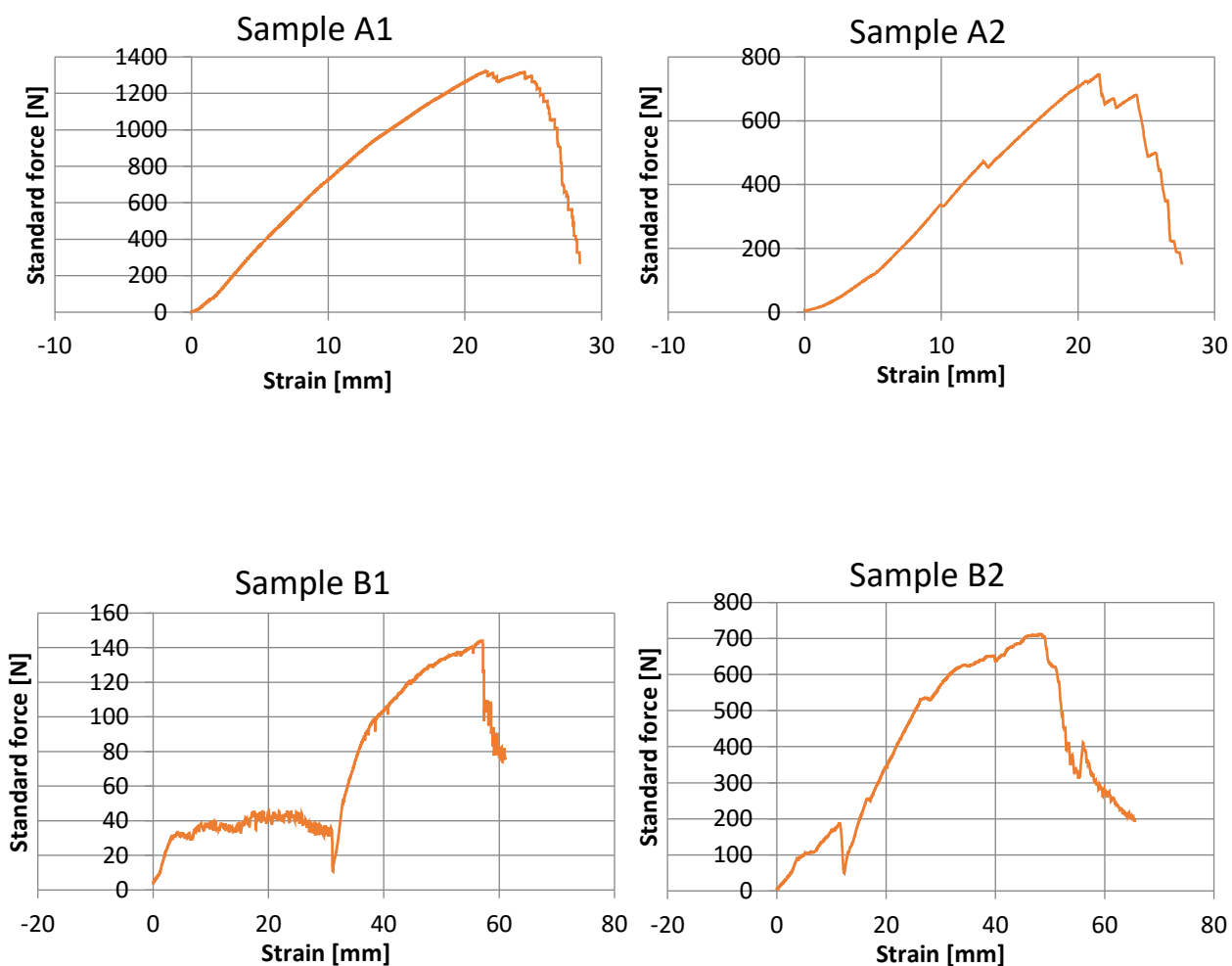


Figure 97: Tensile strength test set up with Cement bags and woven plastic bottles,

The results of the test are shown in the table below:

Sample number	σ_M (MPa)
A1	35.98096
A2	18.63589
B1	3.602694
B2	17.81035
B3	23.72604
B4	11.20785

Table 12: Tensile test results



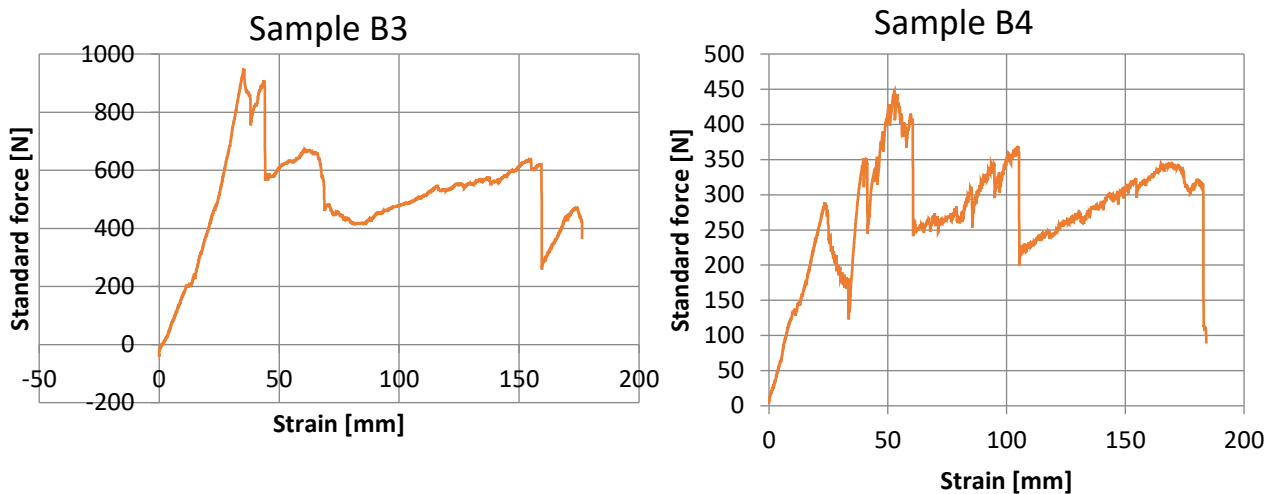


Figure 98: Graphical results of physical testing

According to the literature, the tensile strength of PET is 55-60 MPa, and that of polypropylene is 34.5 MPa. The results show that the woven polypropylene cement bags have an even stress-strain curve distribution with a tensile strength of 36 and 19 MPa for four layers and two layers, respectively. Typically, some people use one bag in the camp, which would be two layers; a second bag is sometimes applied to increase strength. However, the woven plastic had a stress and strain curve with multiple dips and inclines. This may be due to the slippery nature of the PET, as the machine had some trouble gripping it sufficiently. Another cause of this is the weave tightness. Sample B1 was sliced at the end; this reduced the grip between the weave as some parts began to unravel pretty quickly. Thus, it has a meagre tensile strength of 3.6 MPa. The specimen with the highest tensile strength is specimen B3, made of large plastic bottles and held together with additional PET thread.

It is also important to note that the interlocking plastic pieces did not lose integrity after the test, it only unravelled when the PET sliced thread came apart. However, the polypropylene strings unravelled and tore significantly at the end of the test.



Figure 99: Cement bag and woven plastic after the tensile strength testing

In conclusion, the results show that the tighter the weave is, the higher the tensile strength. It can be better than a single layer of a cement bag presently used in the camp. For the woven PET to have the highest tensile strength, the weaving technique must be as tight as possible.

9

Architectural
application



9.1 Introduction

This chapter includes the most crucial steps in the process of the design; it will try to explore and answer the following questions:

What geometry is suitable for a building component made out of woven plastic in the overall building system?

What kind of housing designs can be created based on the building system?

Does the building system complement the existing local building technology within the IDP camps?

Chapter 4 discusses the building technology in the camps; the design brief discusses the building component's general limitations. The tests conducted in the material design chapter show some further restrictions. Based on these three things, the design can commence.

9.2 Panel configuration and geometry

The first thing to note is that the material is intended to be used in conjunction with the building's existing wooden framework and general geometry. A suitable grid for the panel needs to be determined. According to Yohanna, the resident carpenter in the IDP camps, the length and width of each bacha is either 4m or 3m depending on the size of the family. Using this constraint, a vertical grid of 1m is suitable as it is perfectly divisible in both situations, thus avoiding odd panel sizes.

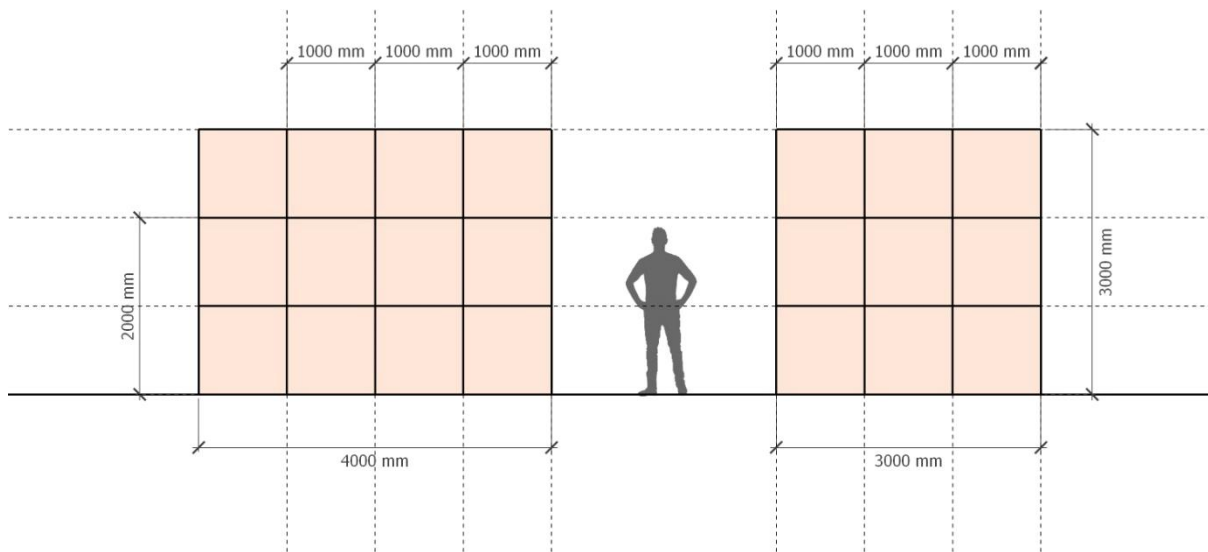


Figure 100: Chosen grid for the panel geometry

Based on the UNHCR requirements, a bacha needs to be at least 2m high. A slope of at least 10 degrees is required for water drainage. A diagonal is cut across the grid to ensure a standardized form of cutting the plastic sheets to optimise panel cutting. By doing this, the slope of a 4m grid length is 14° while the slope of a 3m grid is 18.4° , both of which are suitable for surface runoff.

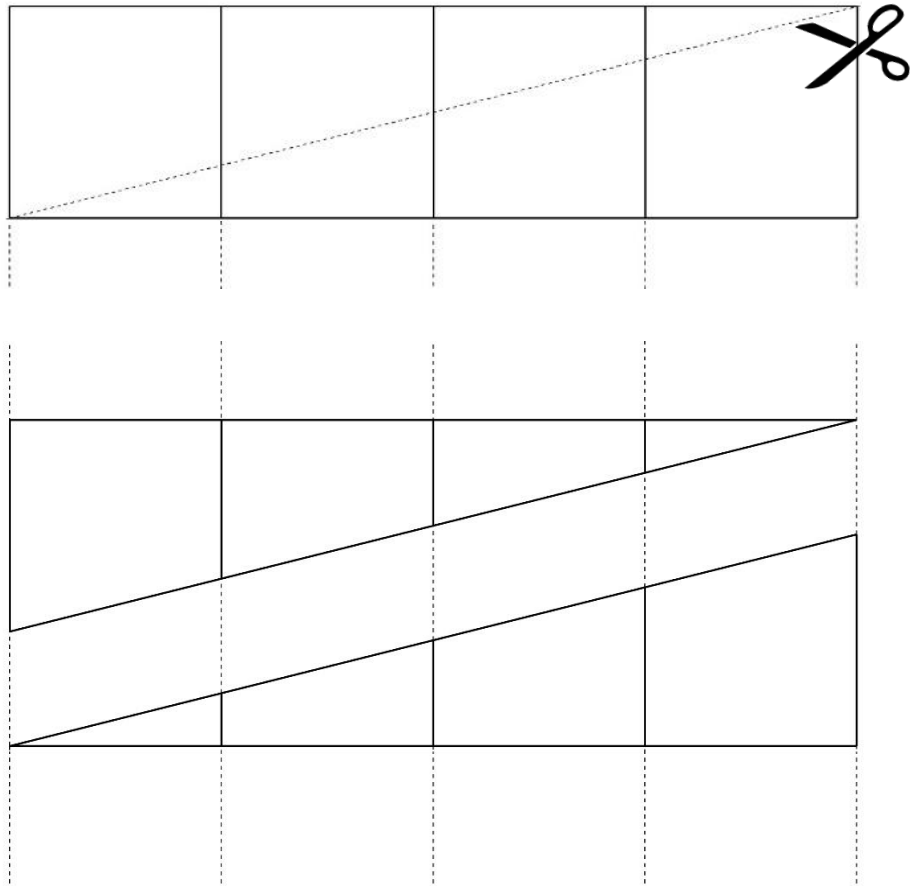


Figure 101: Cutting system for panels

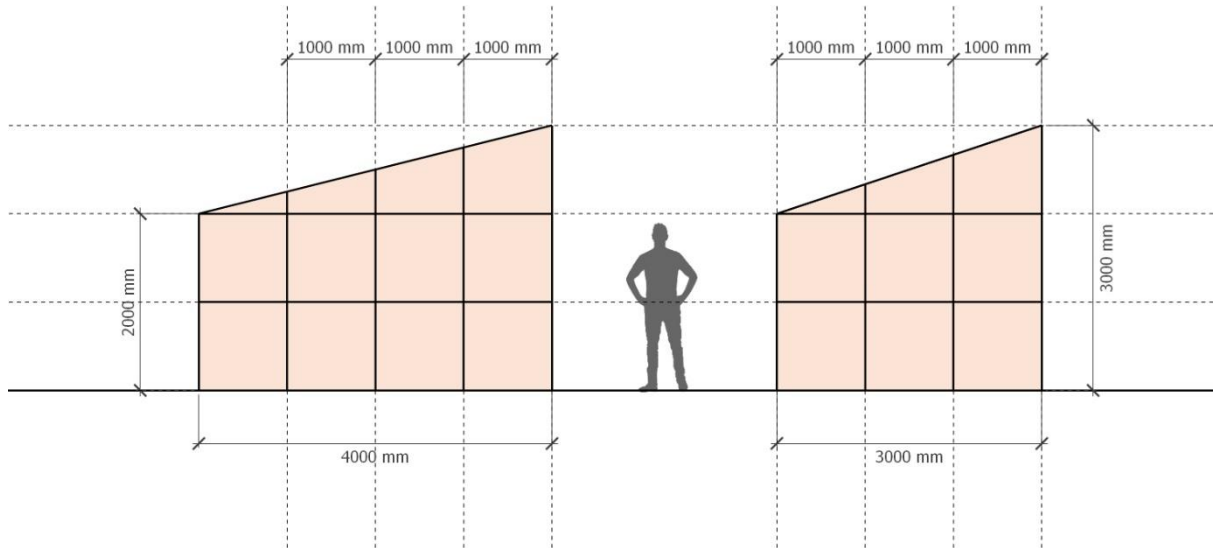


Figure 102: Panel grid with slope applied

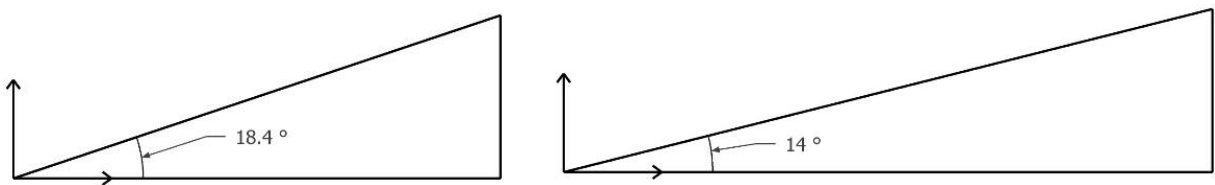
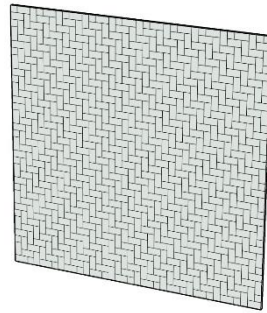


Figure 103: Roof slope angles

There are two main ways for the developed woven plastic to be employed in the design. The first one is by attaching the plastic to the wooden framework directly without any additional support. The second is to combine the plastic with supplementary materials to produce a more solid building component. The two types of components are illustrated in the diagram below.

A: Sheet



B: Composite

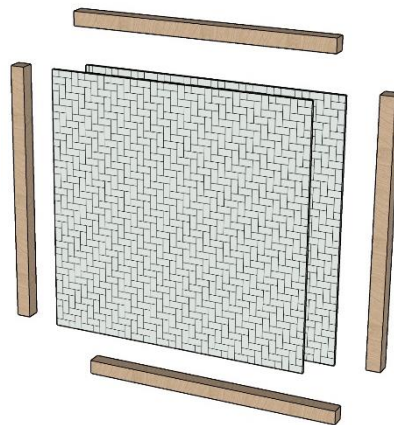
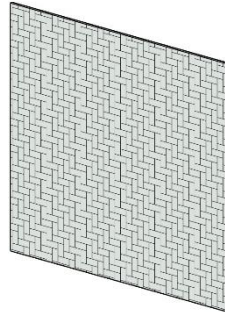
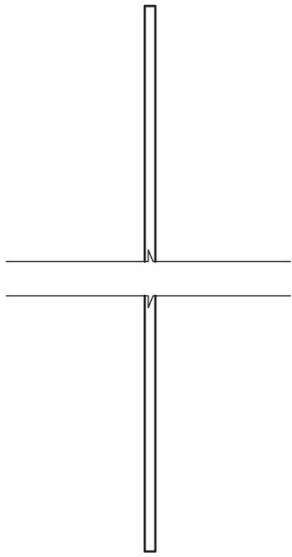
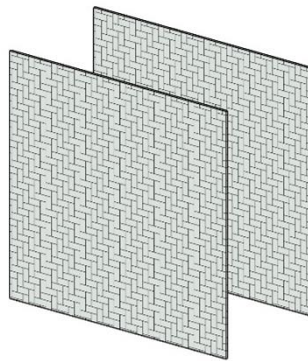
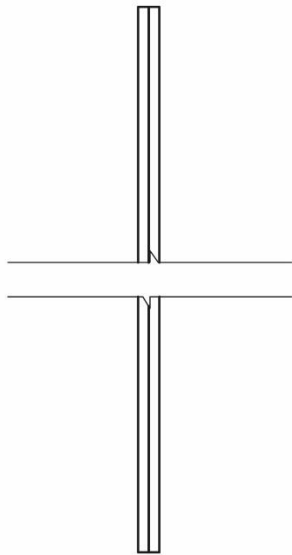


Figure 104: Classification of PET building component.

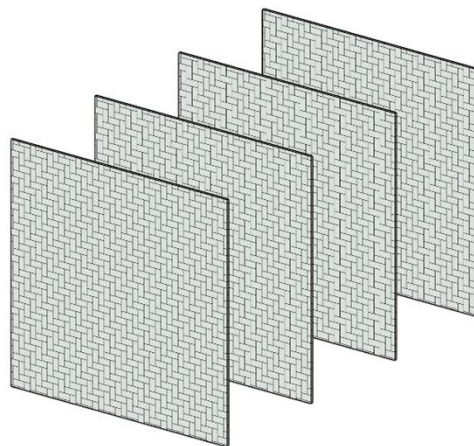
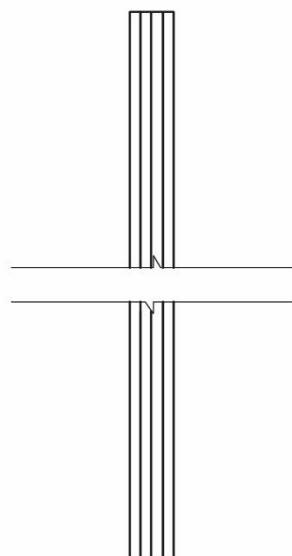
Option A is a simple solution that involves the use of woven plastic sheet alone. It can easily be attached to the wooden framework using plastic capped nails of the PET thread made with the PET slicer. The benefit of this is the lower investment cost because of its simple repetitive nature. Multiple layers can also be employed for higher stiffness, stability, increased climate benefit and decrease in opacity. Option B, which is the composite panel, increases the design possibilities through the use of a cavity between the sheets. An additional wooden frame provides stiffness and makes the building component a more standardized product. Furthermore, it allows for the creation of a cavity that can improve the building's thermal insulation performance, seeing as the heat was a concern for the residents. Different examples of standardized panels are explored below.



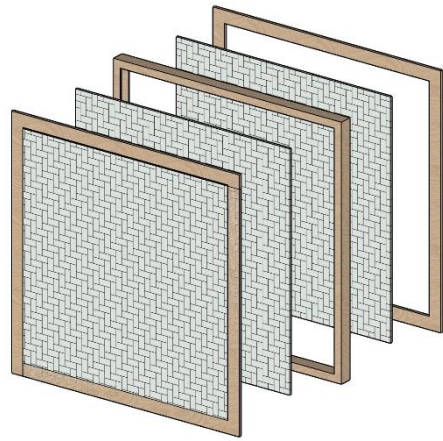
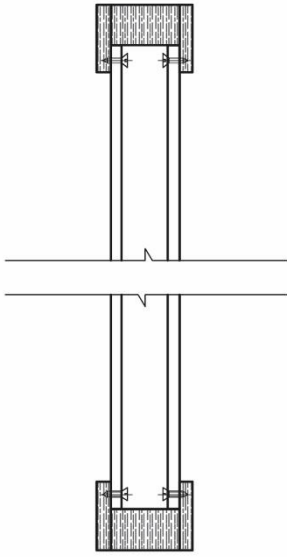
Option A1
Single Plastic layer



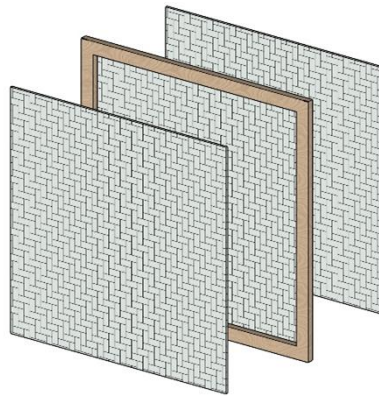
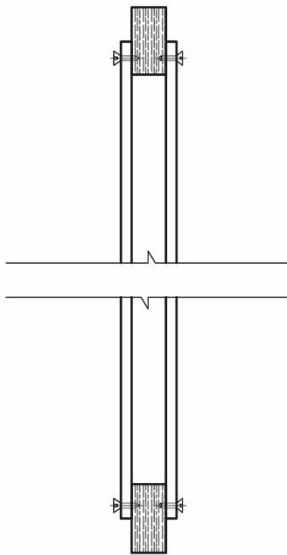
Option A2
Double Plastic layer



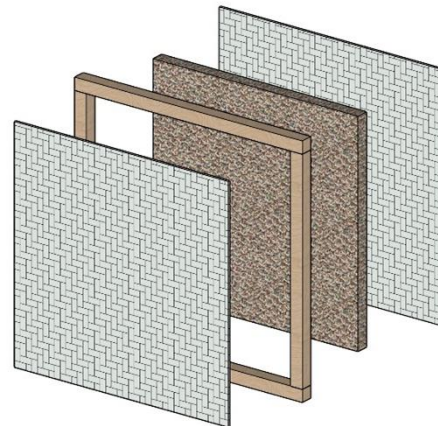
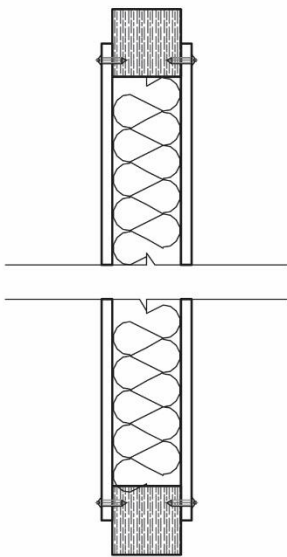
Option A3
Four plastic layers



Option B1
Double layer with
cavity



Option B2
Double plastic layer
with reduced cavity
and wood



Option B3
Double plastic layer
with wood and
insulation

Figure 105: Panel configuration options

Every option explored has its benefits and weaknesses. Option A1 is a single sheet of 8mm thick woven plastic. However, one layer would be too transparent to be applied as a façade element. Option A2 involves using a darker colour as the first layer and a more transparent layer as the second element. Option A3 employs two layers of a darker colour and two layers of a lighter colour. A combination of both is required, mainly because transparent PET bottles form the majority of waste plastic. In order to make the facade opaque enough, multiple layers of woven PET have to be used. This system may not be the most efficient use of the material.

Option B1 employs the use of wood to separate the elements and create a cavity. It involves using a flat wooden panel on the outside, one wooden panel to facilitate the cavity separation on the inside and one more wooden panel on the other side. While it enables creating a cavity, the connection is bulky and requires many production steps that increase the cost. Option B1 is a simplified version with only one wooden panel separating the plastic pieces. Option B3 is the most optimized version with insulation.

The type of insulation to be used is considered. The design brief states that each panel should be as economical as possible. Cheap insulation available in the given context includes natural fibres such as wood chips, wool and sisal fibre. However, to make this as low cost as possible while also reusing plastic as per the design brief, LDPE or HDPE bags can be sliced or cut using scissors into smaller pieces which can then be compressed into the panel. This ensures little to no added cost to the building component while also reusing the plastic. It also guarantees that the element is opaque enough to be used as a façade cladding.

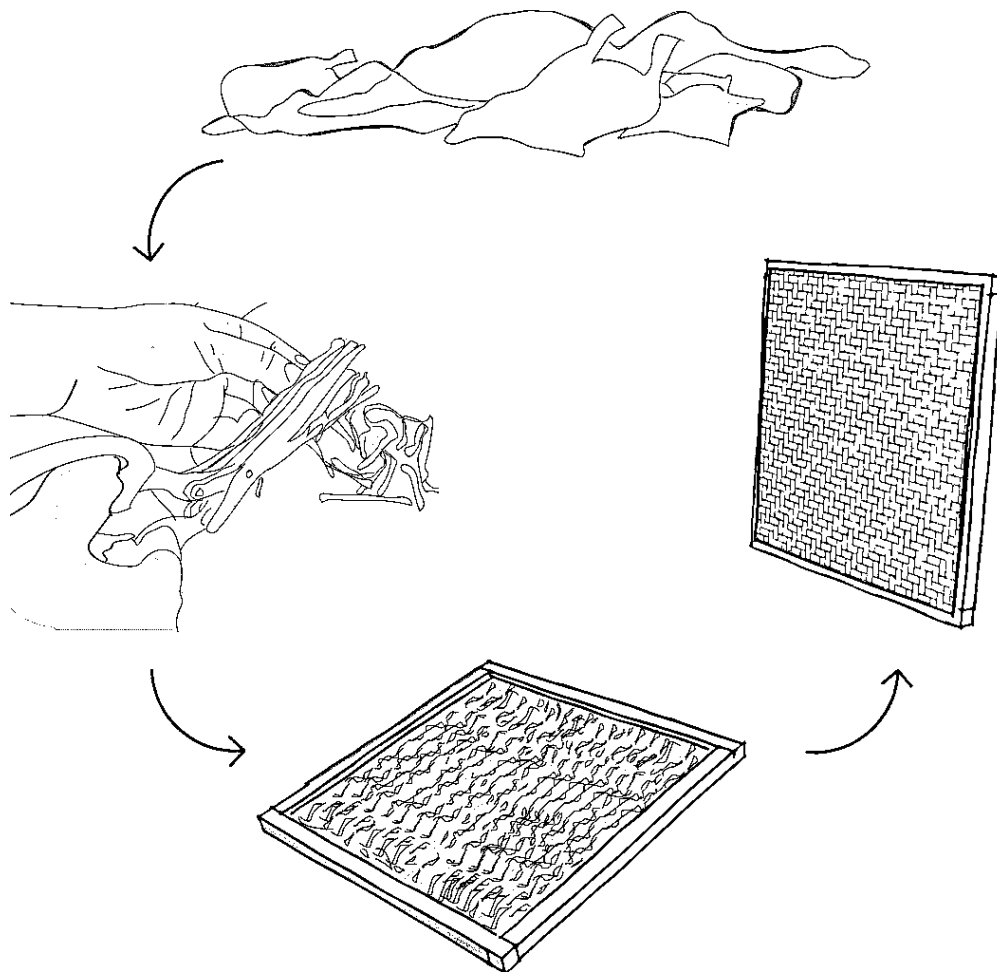


Figure 106: Shredding HDPE to use as insulation.

9.3 Building system

The building system used in the camp employs a wooden framework and a cast concrete base. The building component is designed as a façade cladding element which should be easily demountable as per the design brief. The wooden framework is not standardized; therefore, a suitable grid system needs to be developed. A 1m grid is used vertically and horizontally to ensure a standardized system; it is also a grid that is easy to extend when needed.

Based on the limitations introduced in chapter 8, a whole house or shack can be made from the following elements

Panel- 8mm woven plastic (26 large bottles or 52 smaller bottles/m²)

Wooden panels

Wooden frame columns and beams

Insulation made from sliced plastic – 200 bags /m²

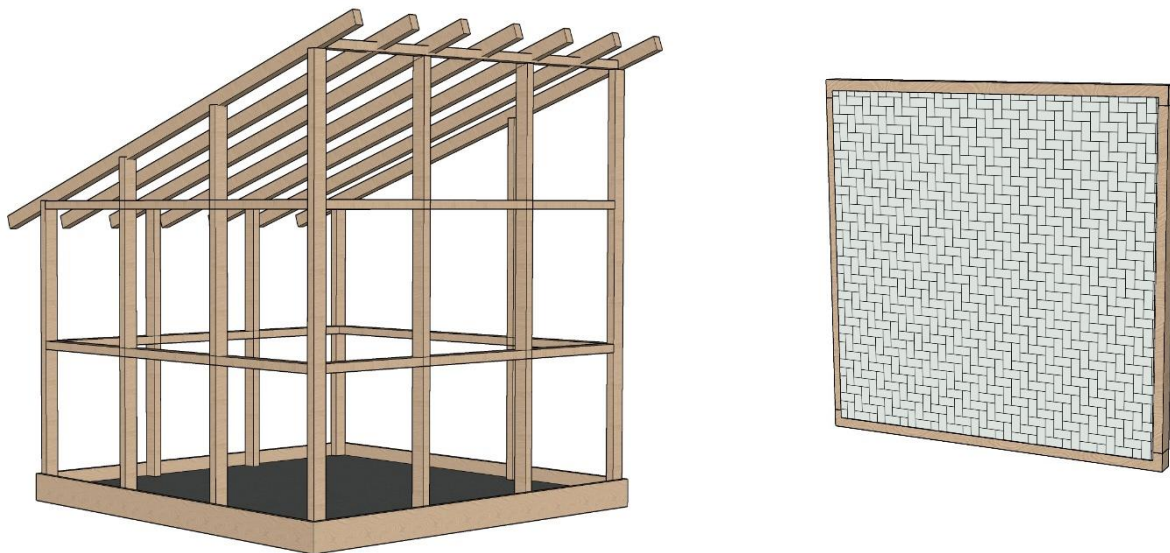
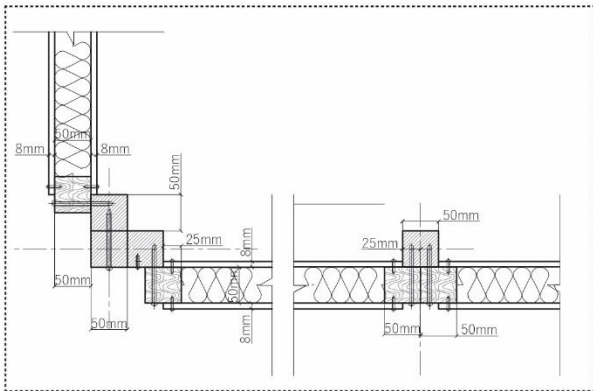


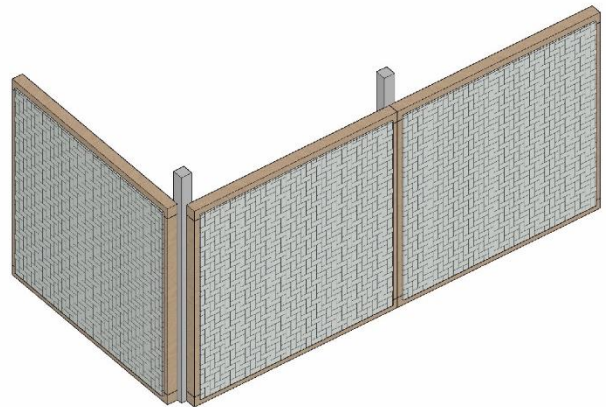
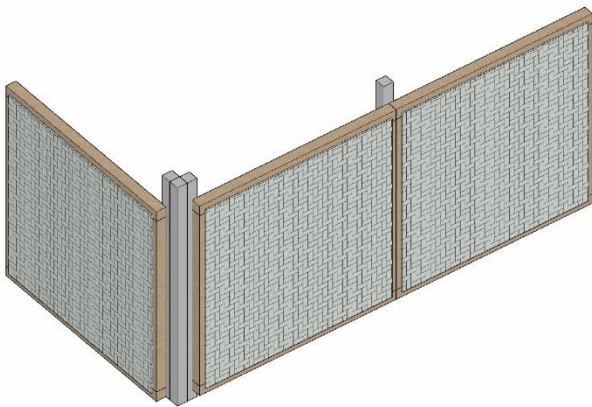
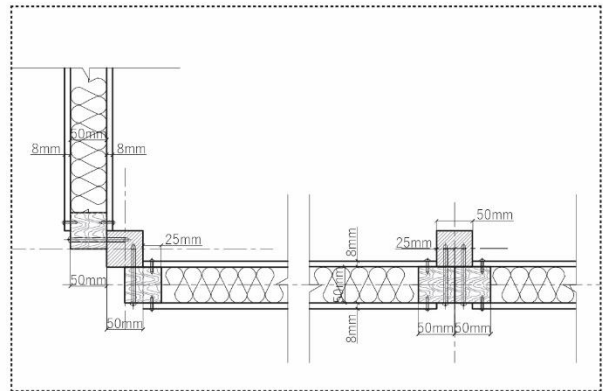
Figure 107: Wooden frame-work and composite plastic facade building component

All these elements can be made using a simple low tech production process and can be connected using 20mm screws for the panels and 40 mm screws for connection to the wooden frames. Using the materials above, the corner joint and the connection to the wooden frame are critical to ensure that the building system can be incremental over time. Different possibilities for the joints using a composed shape are studied.

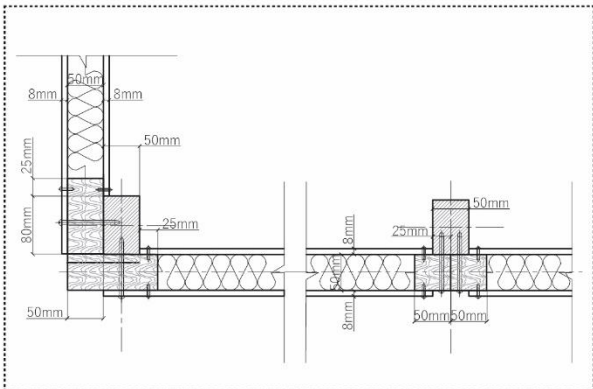
Option 1



Option 2



Option 3



Option 4

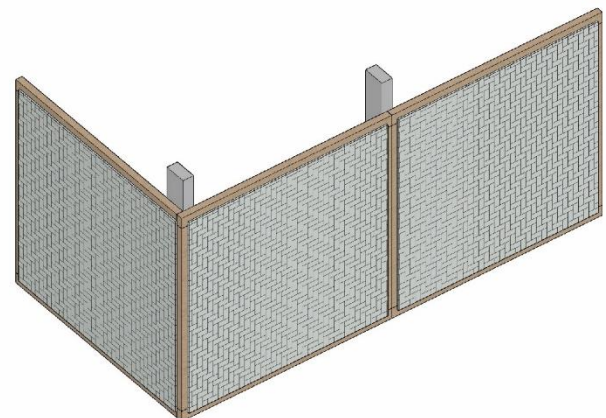
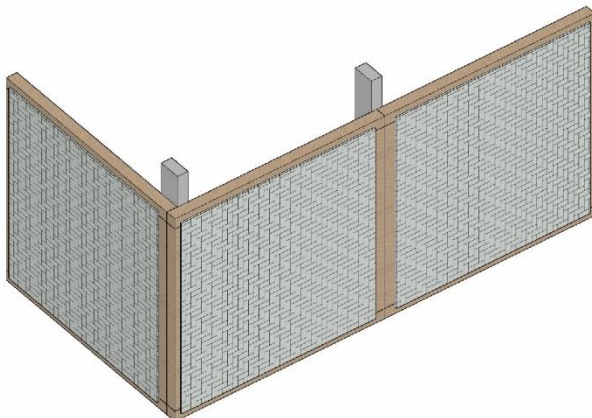
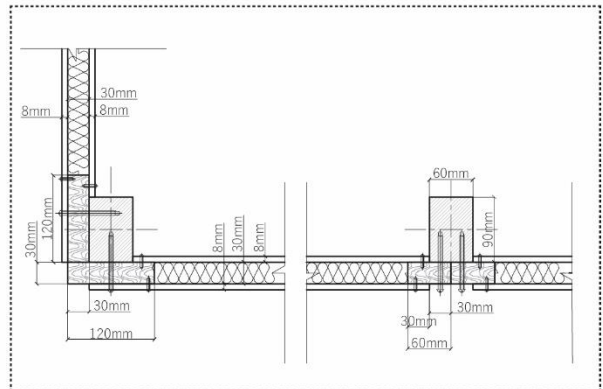


Figure 108: Panel connection options

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

Option 2 connects the corner panels to only one column; this reduces the amount of material used; however, the column is still exposed. This may result in unnecessary gaps, and the look of the joint is not as neat as it could be.

Option 3 ensures that the corner joint is closed and the joint is neat. This also reduces the amount of materials used, and the connection with the screws is more solid than the first two options. However, there are variations in the thicknesses.

Option 4 shows the same corner connection as option 3 but with a 30mm thick wood panel instead of 50mm. The column sizes are also increased to 60x90mm from 50x80mm. This helps to standardize the measurements and provide enough allowance for the screws to be connected to the structure. The major issue with this is that it creates corner panels that have different dimensions. The intention is to make the panels as standardized as possible to avoid wastage and ease the construction.

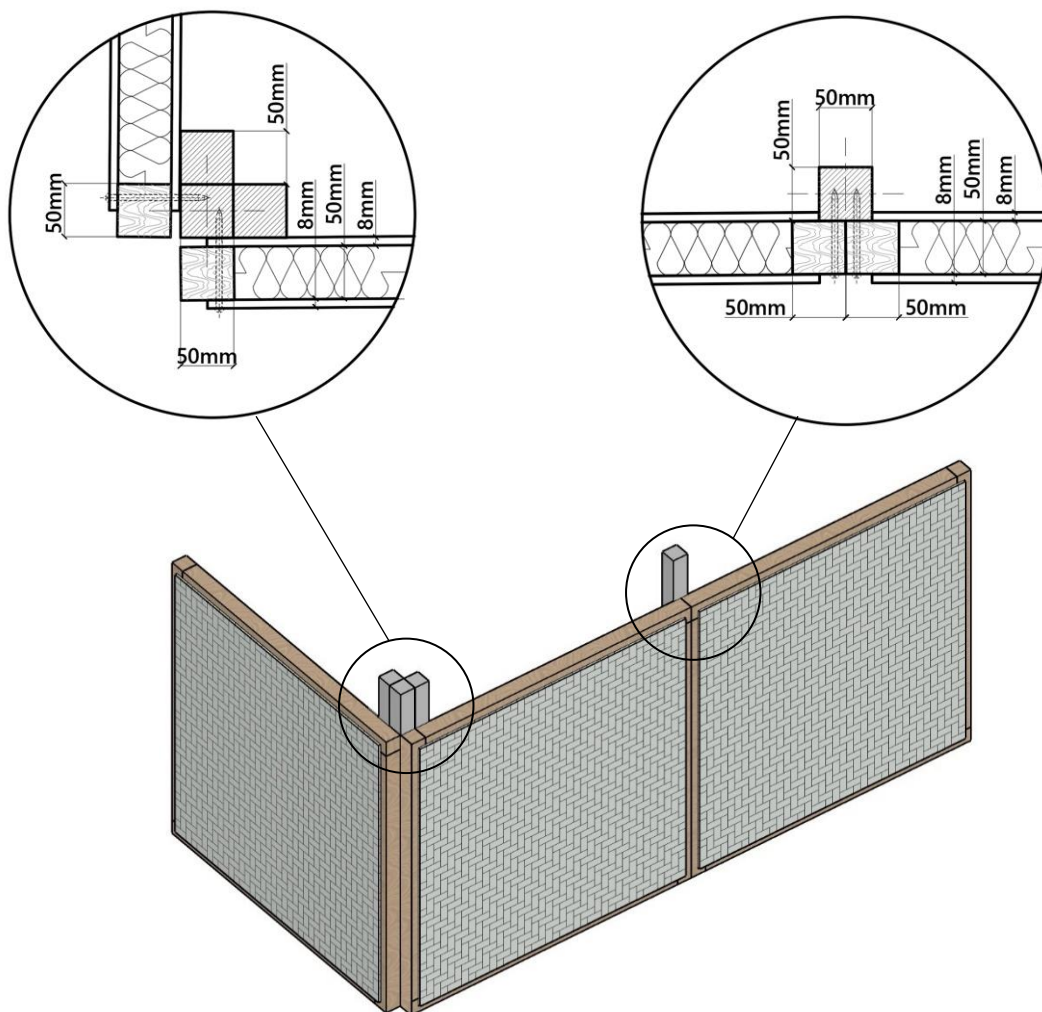


Figure 109: Chosen panel column connection

Option 5 shows an optimum connection with a corner column made of 50mm thick wood and panels made from 50mm thick wood. There is no variation between any of the building components, thus increasing the ease of construction, assembly & disassembly, and the building system's incremental nature. The grid of the building system is illustrated in the diagram below.

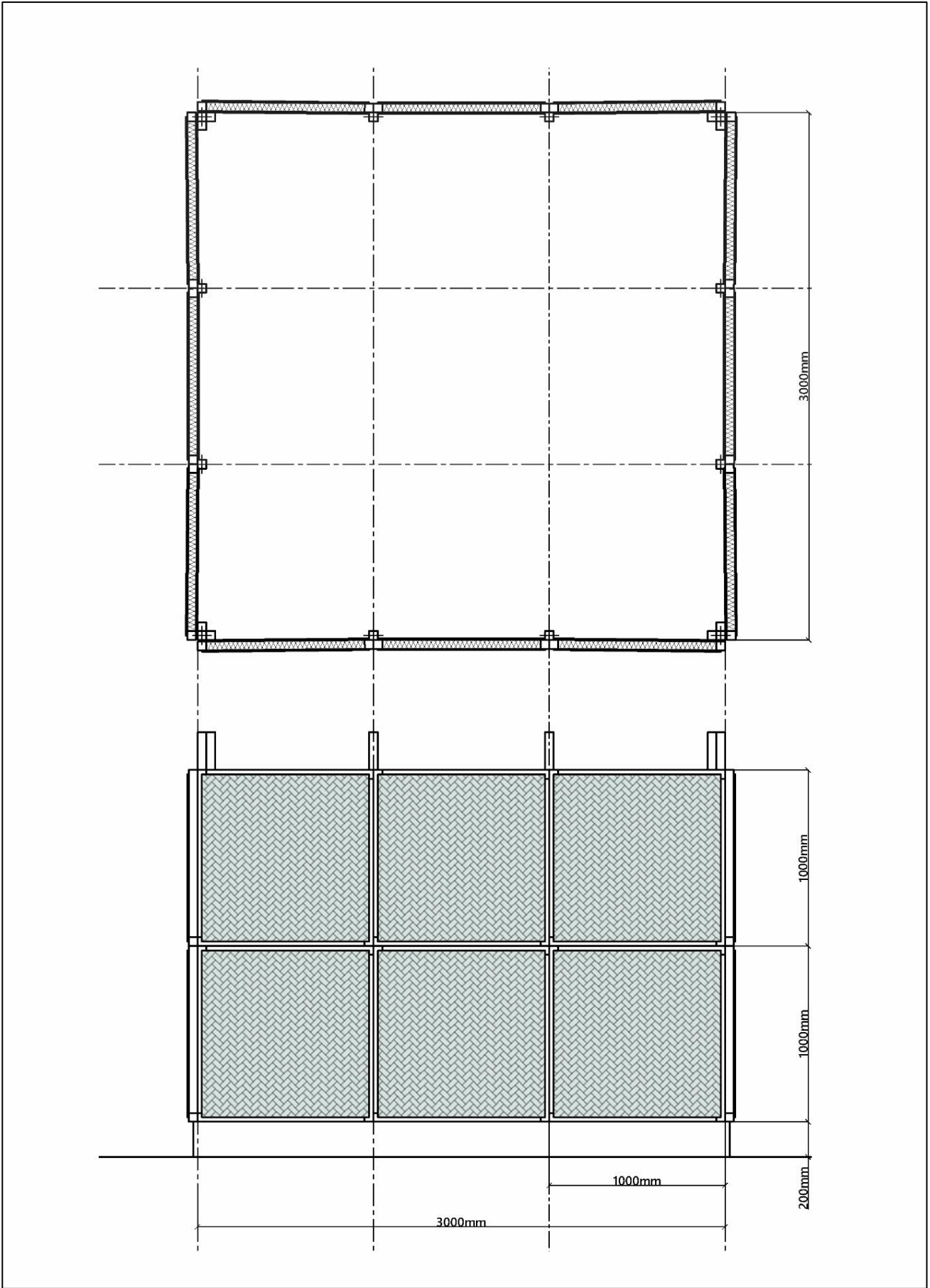


Figure 110: Grid system and elevation

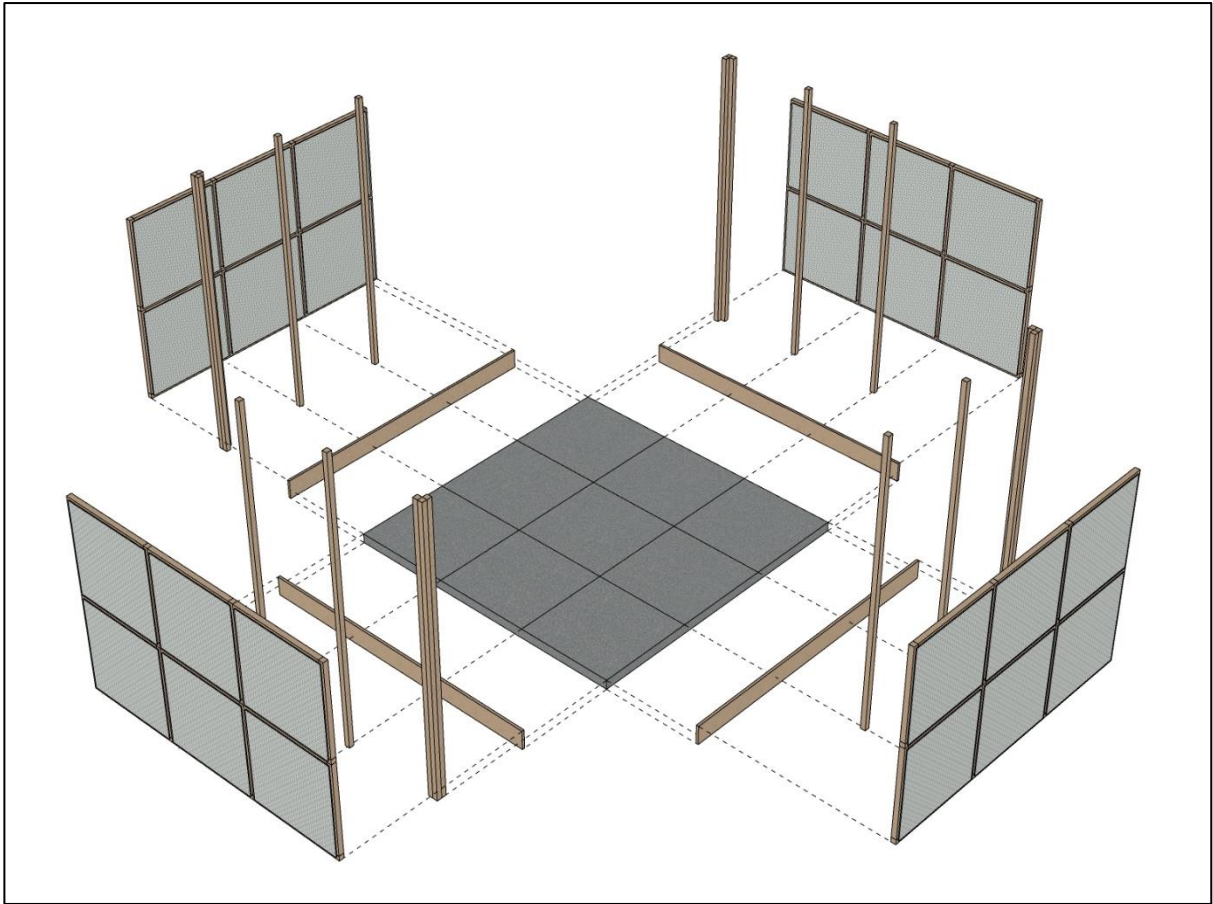


Figure 111: Exploded axonometric view of the building system.

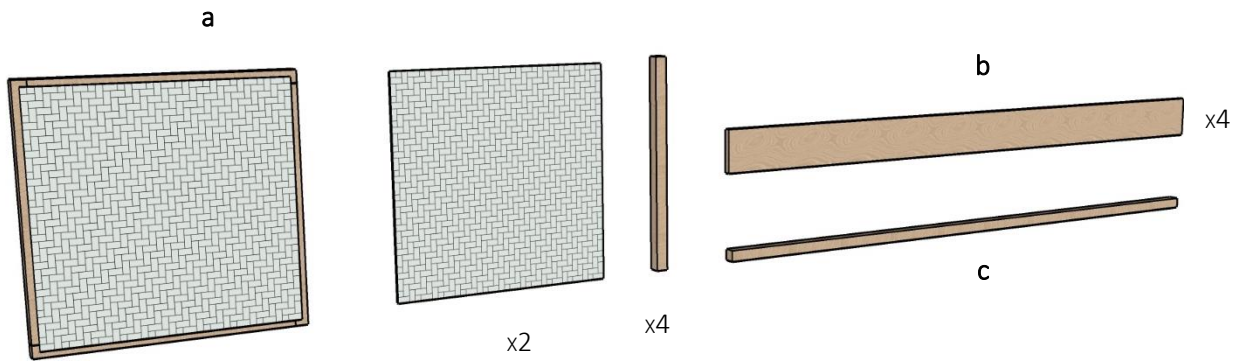


Figure 112: Building system components

There are four main components in this building system:

- a. 950x950 woven PET panel, 50x50x950mm wooden panel
- b. 25x200x300mm base wooden panel
- c. different bar lengths 50x50mm thickness

9.4 Bioclimatic building design

According to the literature research, the building should be designed using certain climatic principles in a particular hierarchy. The design will follow these step by step. The first iteration of the design will be for a 3m x 3m bacha unit, as that is the minimum size of the housing unit in the IDP camp.

Step 1: Site selection and orientation

The site is located in Abuja, with a hot and dry climate. The site itself is not straight facing directly north. It is placed at an angle, as shown in the diagrams below.

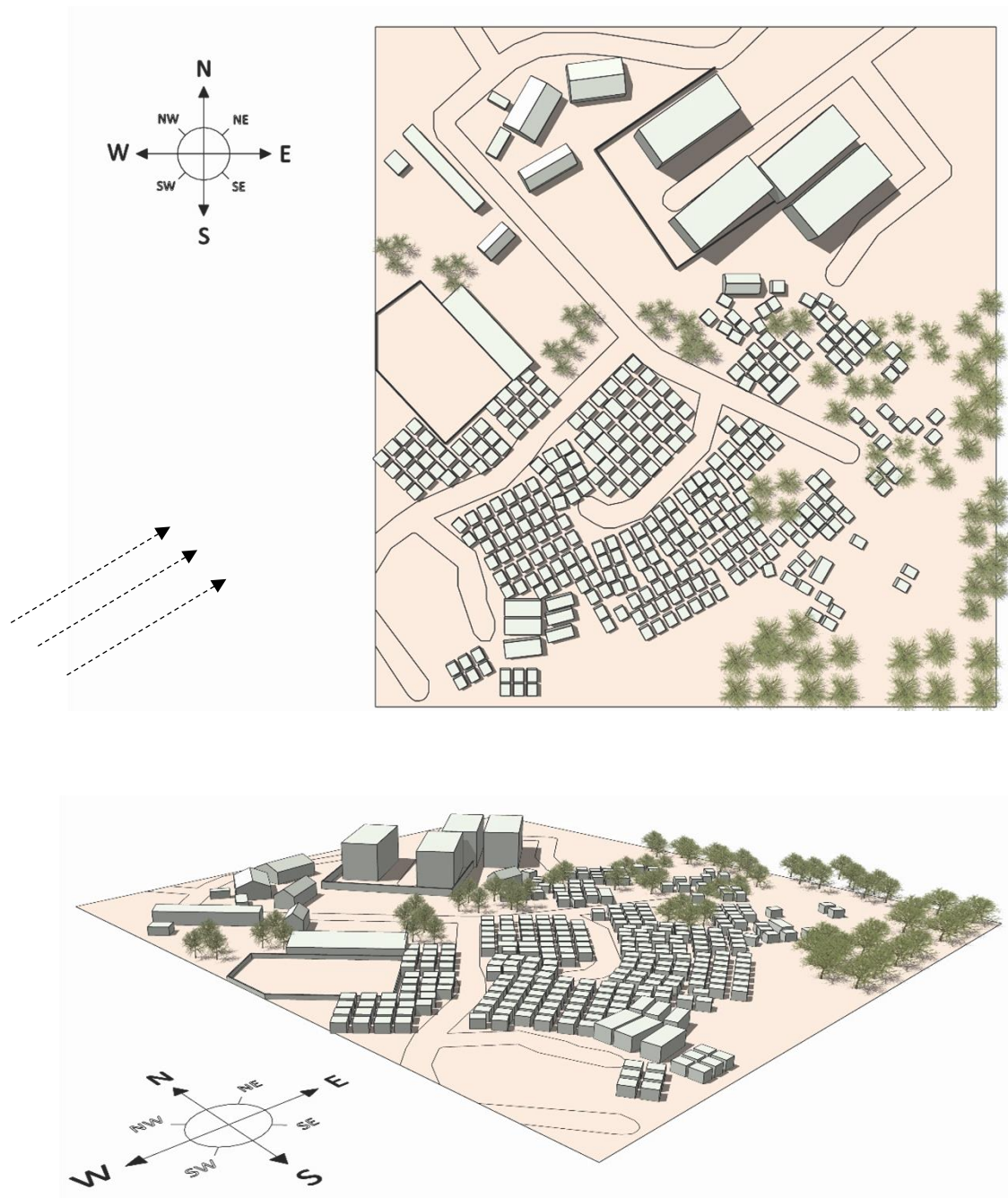


Figure 113: Site model with cardinal points and wind direction

The wind rose for Abuja shows that the strongest prevailing winds are the South Southern and southwest winds. The site is already rotated in a southwest direction; therefore, each bacha in the design should correspond with the prevailing wind orientation, as shown in the diagram below.

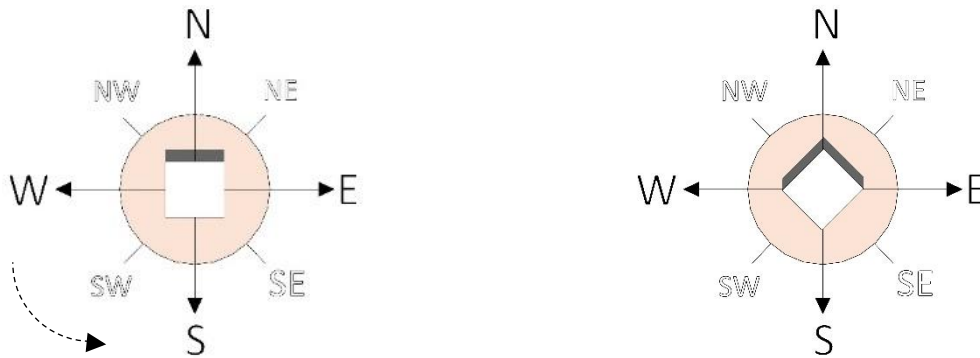


Figure 114: Rotating the figure in the wind direction

For the orientation of the windows and doors, openings on the east and west-facing windows should be avoided, while windows on the North and South should be placed with appropriate shading. Seeing as the building is at an angle, the openings are positioned more on the Southeast and Northeast as the western façade has the highest accumulation of solar irradiation all year long.

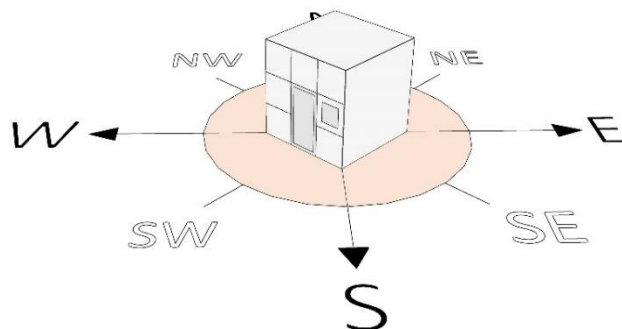


Figure 115: Placement of openings in the wind direction

Step 2: Building form

The bacha basic unit is 9m², and this is distributed as a compact cuboid volume; thus, the solar energy is concentrated on the smallest area possible. In order to maximise the effect of the orientation on the direction of the prevailing wind, another opening on the opposite end of the structure is also included as far east as possible to reduce the solar gain in the building.

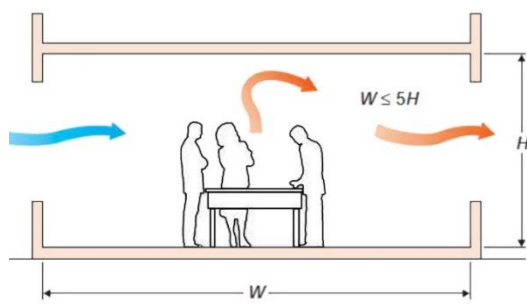


Figure 116: Cross ventilation

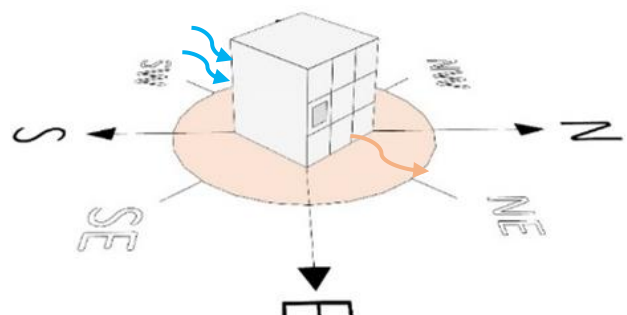


Figure 117: Placement of window on the opposite wall for cross-ventilation

A buffer space can also be added on the south side entrance in the form of a veranda to reduce to help regulate the indoor temperature as it is not always occupied.

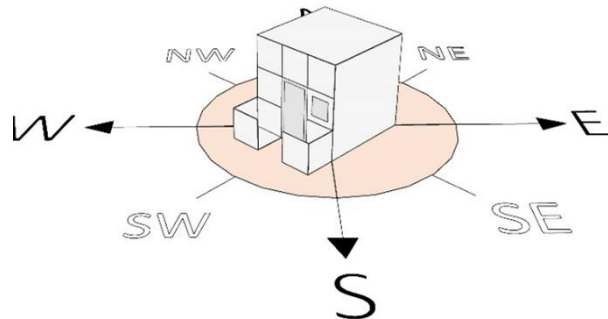


Figure 118: Buffer space

Step 3: Building envelope

The building required shading on both the South and North facing façade. As the site is rotated, the angles to consider will be the lowest angles of 20° E/W of North and South. This will ensure that the house is shaded sufficiently all year round.

Façade orientation	Due North	20° E/W of North	Due South	20° E/W of South
Abuja (Lat 6°N)	73°	62°	57°	49°

Table 13: Lowest sun angle from horizontal to avoid all direct sunlight between 9 am and 3 pm in Abuja (Arup (Madrid & Lagos offices), 2016).

If window height = 1.8m

Roof gutter on South facing façade = 3.3

Hw South

Roof gutter on North facing façade = 2.3

Hw North = 3.3-1.8

= 1.5m

Hw South = 2.3 – 1.8

= 0.5m

Using the formula for overhang $hr = hw * \tan (90-Ls)$

Hr North = 1.5 * tan (90-62)

= 0.8m

Hr North = 0.5 * tan (90-49)

= 0.4m

This means that the South facing façade requires an overhang of at least 0.8m and the North façade requires an overhang of at least 0.4m. First, a suitable slope has to be added for rainfall runoff. This is done according to the panel configuration stated earlier in 9.2.

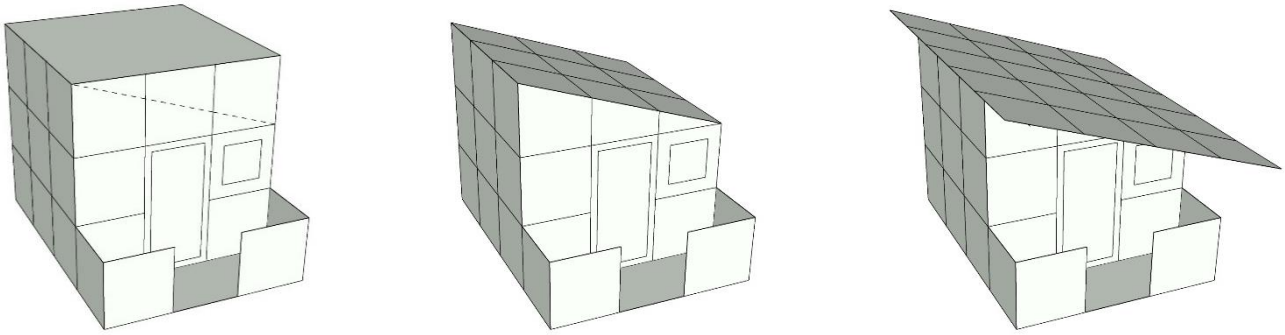


Figure 121: Overhang placement

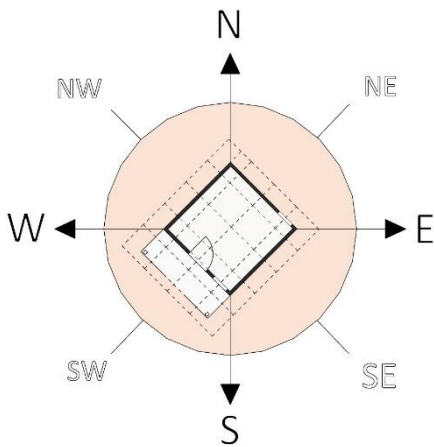


Figure 120: Optimal climate house in Kuchingoro IDP camp

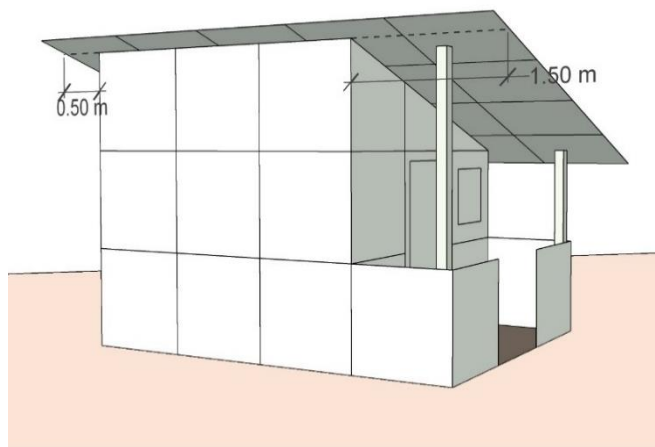


Figure 119: Overhang dimension

Step 4: Passive cooling

Regarding thermal cooling, the panels are insulated using shredded plastic bags, as mentioned earlier. The IDP camp already uses cast concrete as a base for some of the houses in the IDP camp. This will provide enough thermal mass for the room. The concrete can be cast with wooden planks on the outside to ensure that it is also insulated from the outside. The u-value of the wall is calculated on the software design-builder to be around $0.432 \text{ m}^2\text{K/W}$. This is comparable to that of a 225mm concrete, which has an R-value of $0.45 \text{ m}^2\text{K/W}$ or a brick wall with an R-value of $0.27 \text{ m}^2\text{K/W}$. It is also more than twice as good as the R-value of the polypropylene bags at $0.21 \text{ m}^2\text{K/W}$.

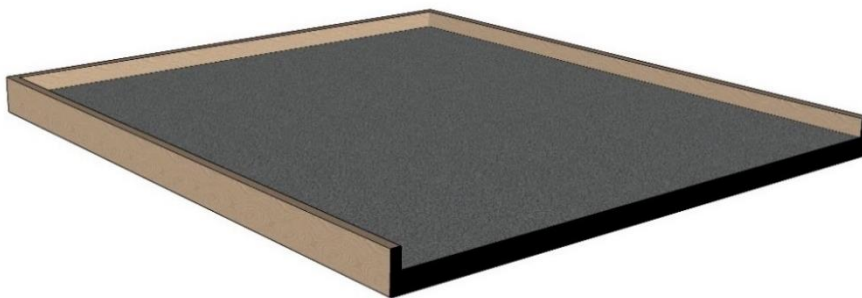


Figure 122; Concrete base with wood panel insulating it

9.5 Architectural design (different family scenarios)

Various enclosed building forms can be made using the defined building system. According to the design brief, the building component' is defined as any module which can be used repetitively as a building material, functioning as either a structural material or cladding material. It should be able to protect the inhabitants of the IDP camp against the weather elements. The fact that the housing design is a system rather than a fixed building ensures that different housing solutions can be employed based on the family type. The interviews conducted in the camp showed that there are multiple family types; thus, the building system has to adapt to necessity. The housing types will be adjusted for three different family units.

Type A – Single parent with one parent and max two children

Type B – Nuclear family unit with few children

Type C – Large family unit



Figure 123: Family types in the camp

The bacha units are usually built after the materials have been gathered, then the shack is constructed within a day or two. The basic bacha unit should satisfy the primary priority: a shelter and space for people to sleep and store essential belongings. Thus, the first bacha unit on arrival in the camp starts with one functional box with enough space for one double or two single beds is enough room for a small family of two or three to reside. The sloped roof allows for rain drainage, and windows are placed for ventilation and lighting. After some time, it can be expanded to include a defined balcony space and a small kitchen. By doing this, the unit is at the maximum 4x4 requirement as stipulated by the camp conditions.

TYPE A

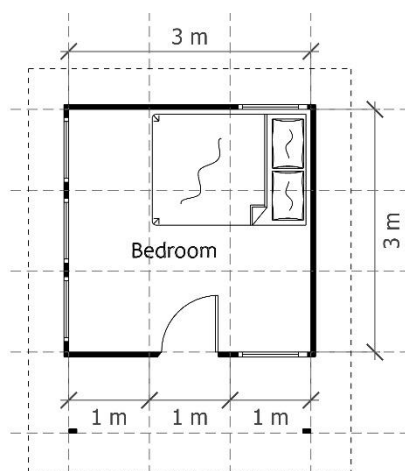
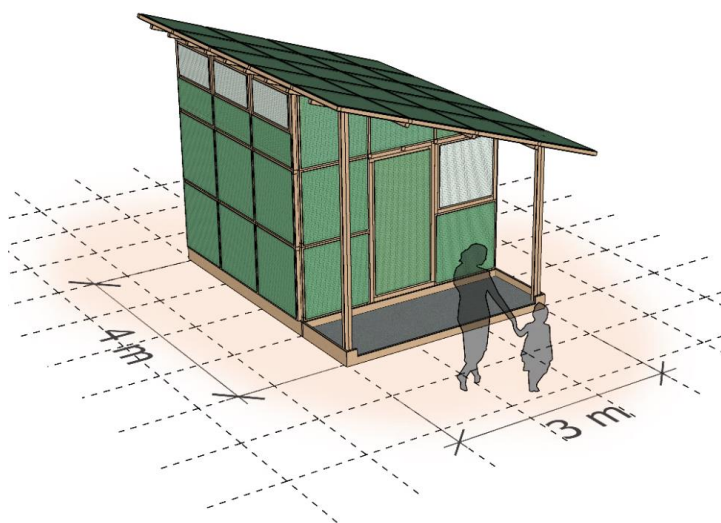
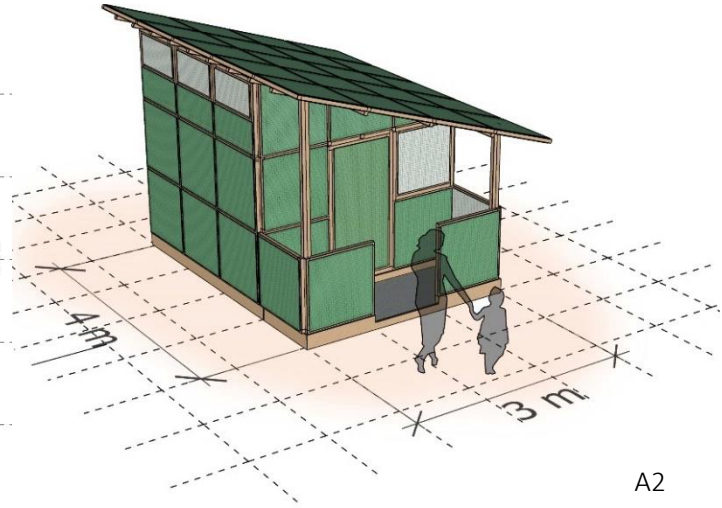
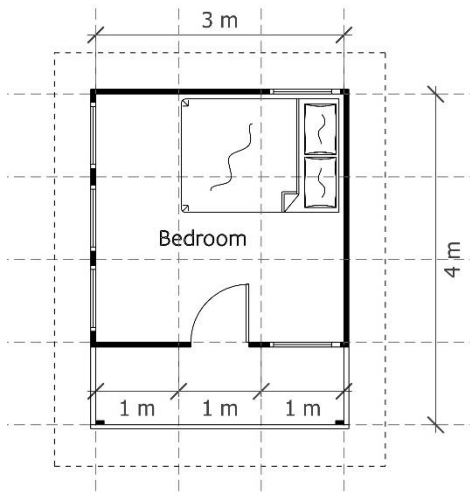


Figure 124: Bacha A2 configuration

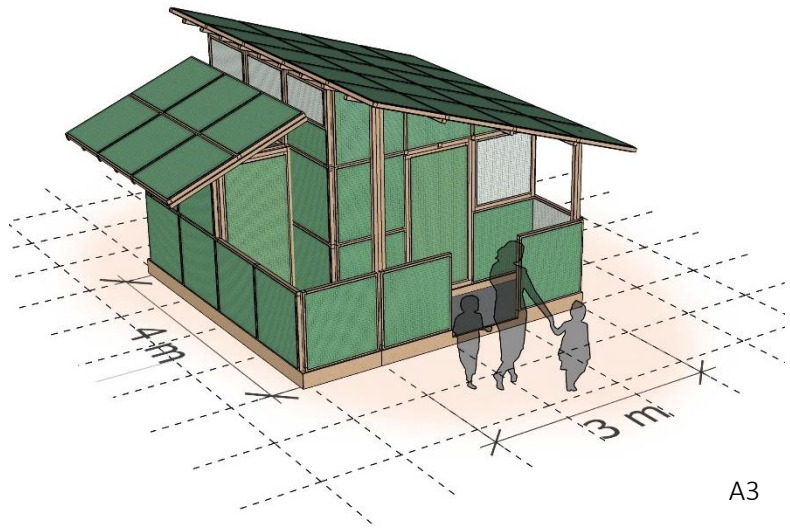
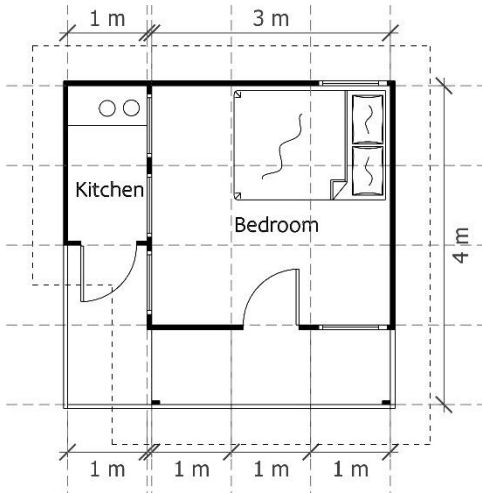


A1



A2

Figure 127: Bacha A2 configuration



A3

Figure 126: Bacha A3 configuration



Figure 125: Section through Bacha A3

TYPE B

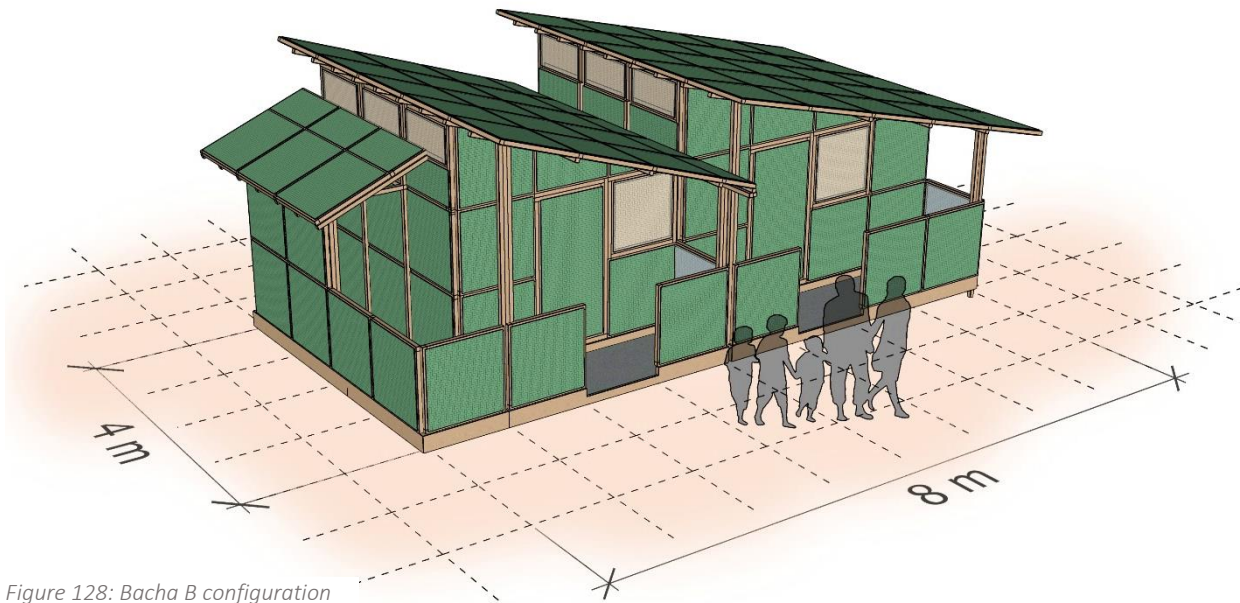
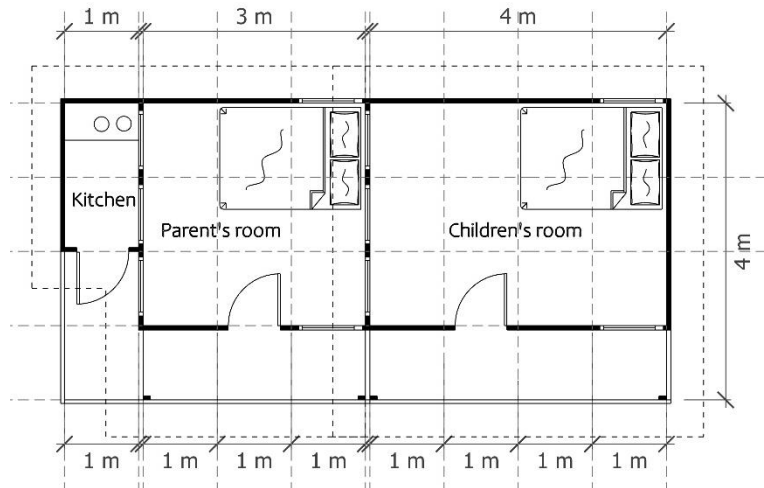


Figure 128: Bacha B configuration

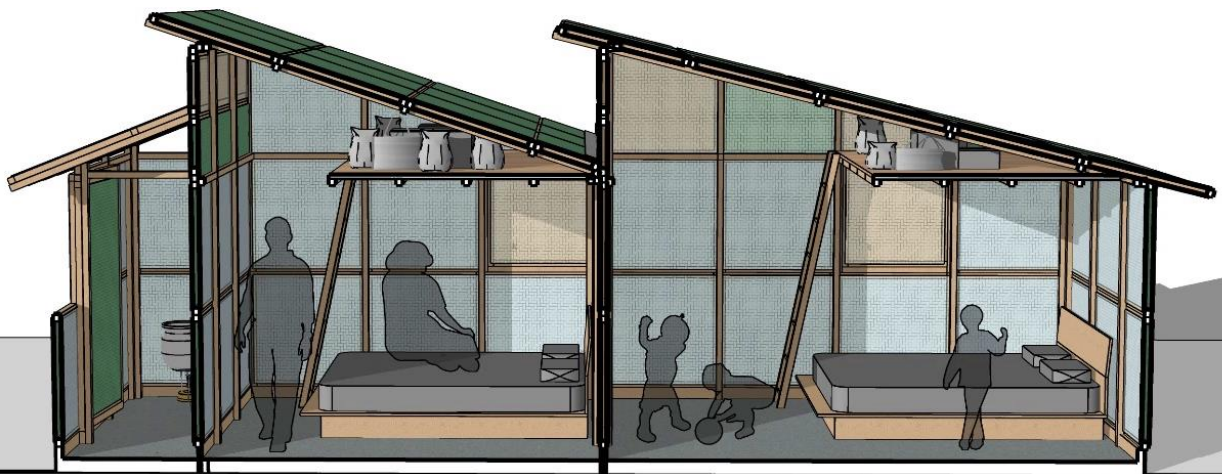


Figure 129: Section through Bacha B

TYPE C

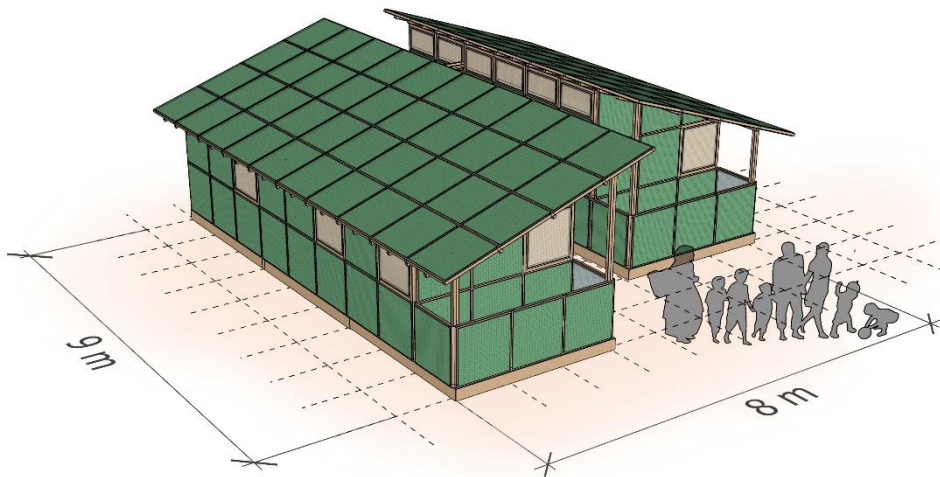
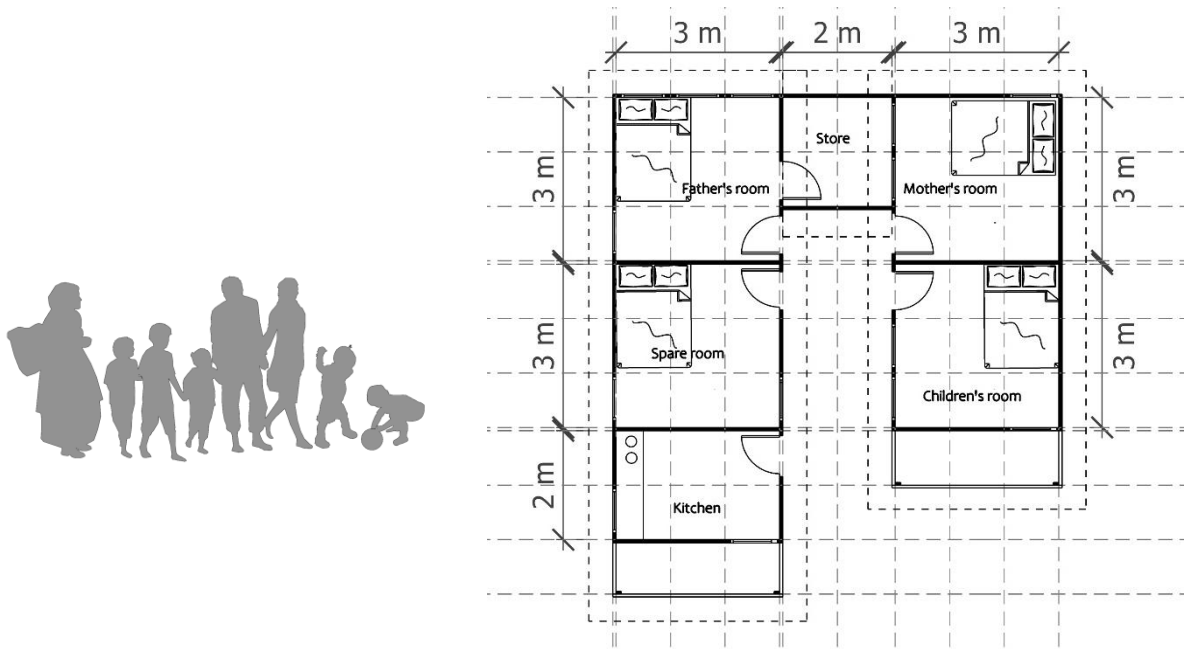
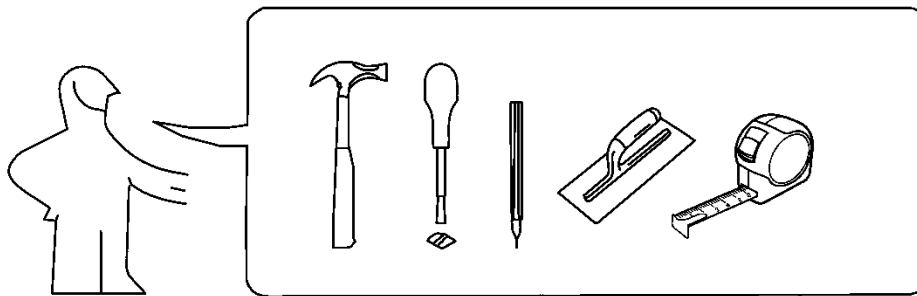
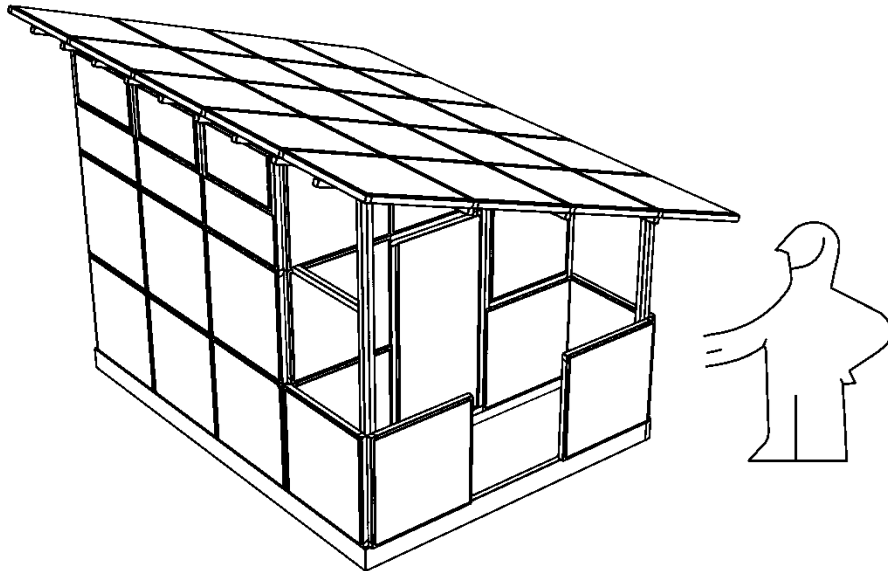


Figure 130: Bacha C configuration



Figure 131: Section through Bacha C configuration

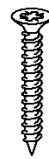
PLASTIC BACHA



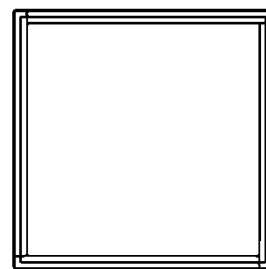
x8



x>100



x>100

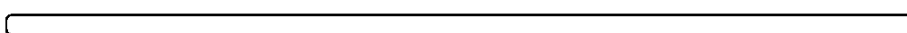


x50

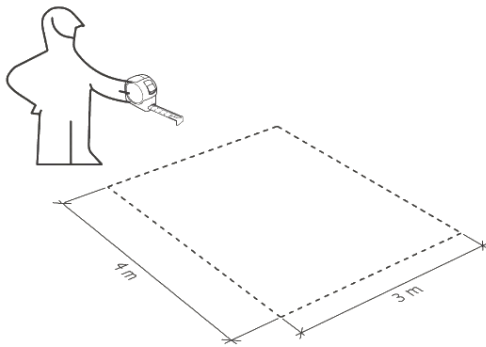
x>4



x>40

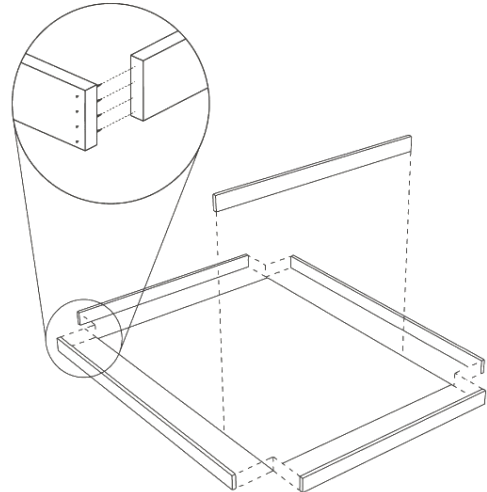


1



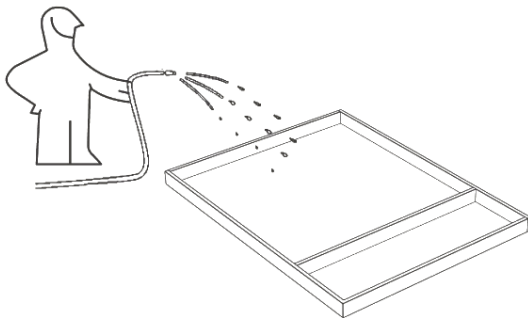
Set out the dimension of the bacha

2



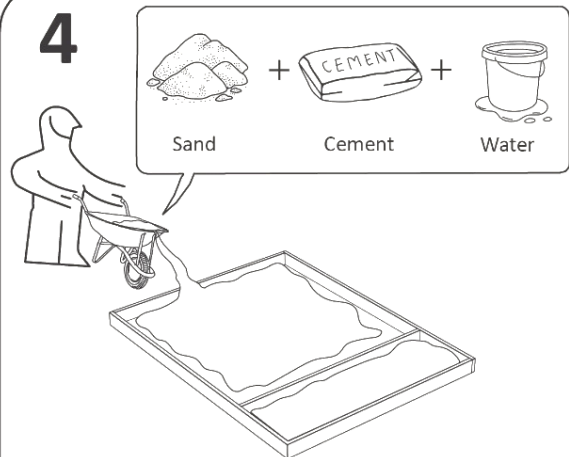
Attach the base panels to get the concrete formwork

3



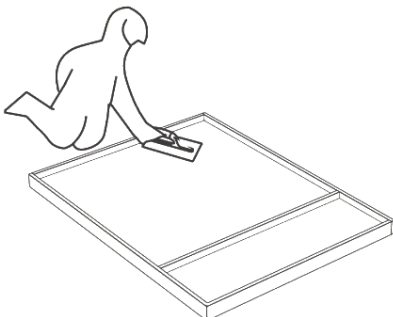
Water the ground to allow the soil to expand

4



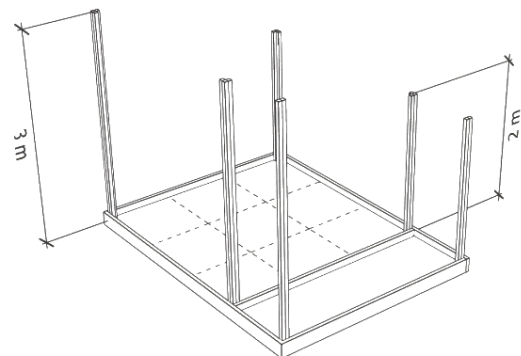
Mix appropriate amount of cement, lime, sand and water according to the instructions on the bag until smooth. Pour the mortar inside the formwork

5



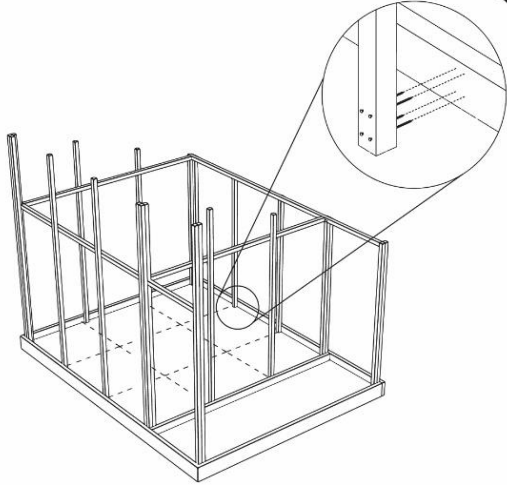
Level the concrete with a trowel and allow to dry

6



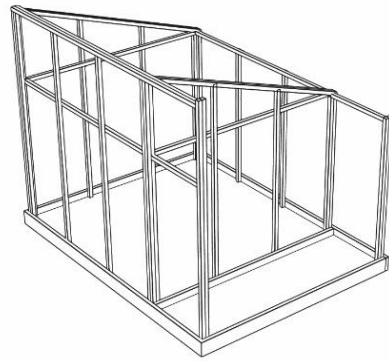
Place the columns at the base of the dry concrete and attach to the wooden plank

7



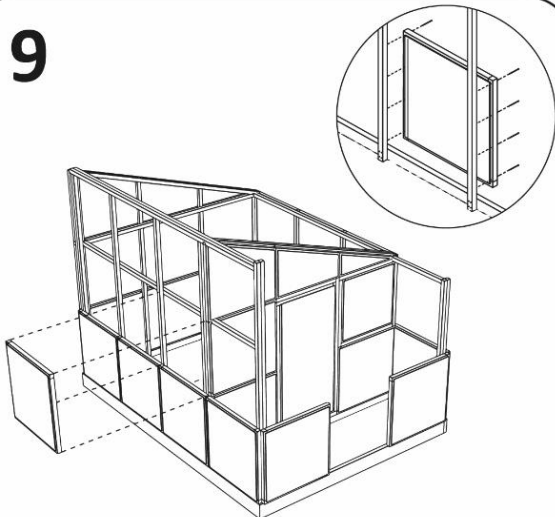
Attach the rest of the columns and connect them with horizontal beams

8



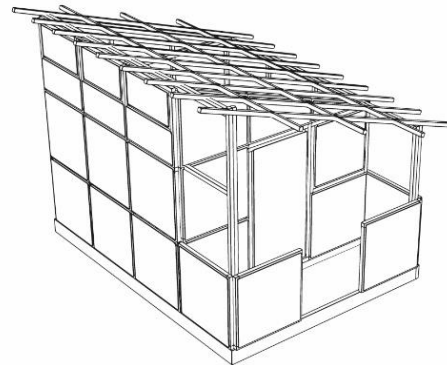
Attach the sloping beams to complete the frame

9



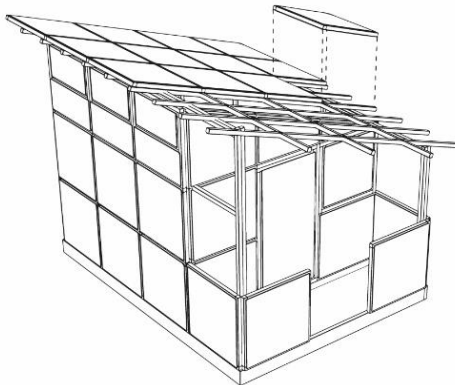
Attach the panels to the columns using screws

10



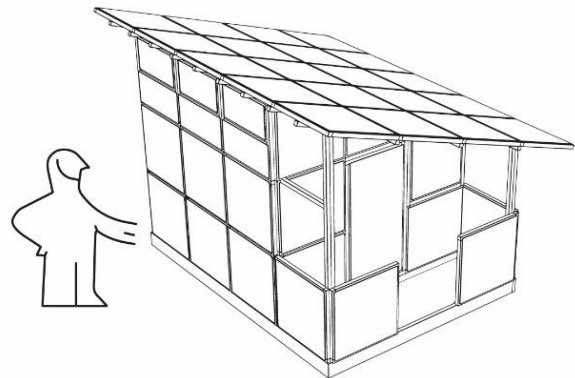
Place the roof beams spaced at 1m to accommodate the panels

11



Place the roof panels

12



The complete bacha

Figure 132: Building manual

9.7 Physical prototype of the final design

A physical model was made to determine the feasibility of the design, possible improvements and select the number of bottles needed for a panel. The information derived from the physical model culminated in creating an excel sheet, as shown in the appendix; it includes the number of bottles required for a panel, its weight, and calculation of the number of bachas that can be built based on scaled-up estimates. About 60 large bottles are needed for a 400x400mm panel. The configuration is shown in the image below:

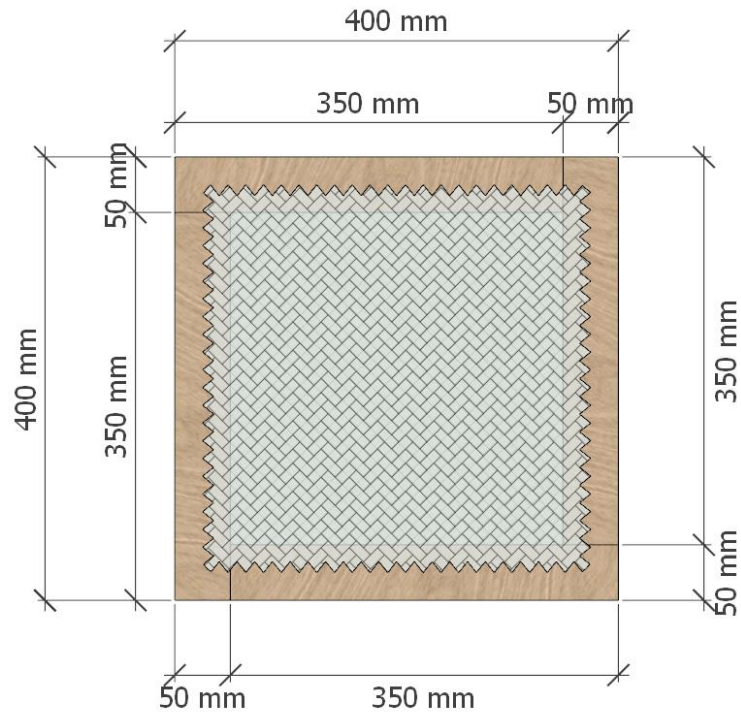


Figure 133: Panel prototype configuration



Figure 134: Prototype showing the woven clear PET



Figure 136: Prototype showing the woven green coloured PET



Figure 135: Panel showing the thickness of the plastic and wood frame

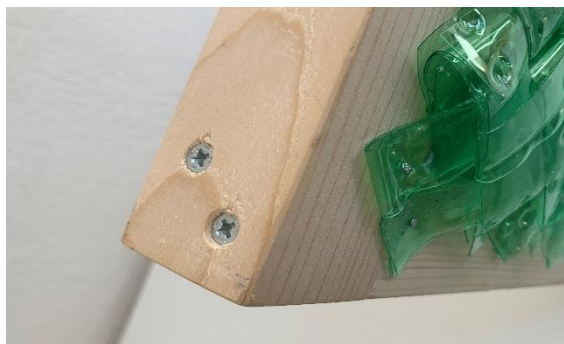
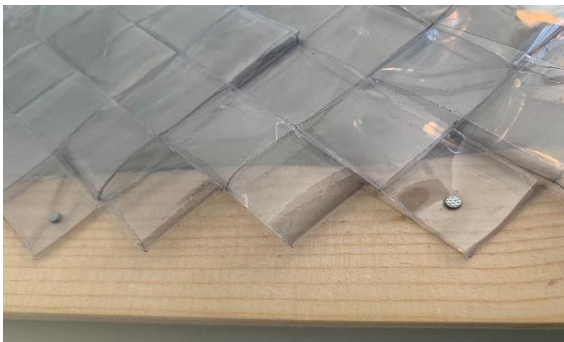


Figure 137: Connections using nails and screws

The major takeaway from building this model is that the coloured plastic is thicker and is not as easy to lay flat on the wood. Therefore more nails will be required to hold it down. It is also advisable to leave a little allowance while weaving to allow plastic contraction when heat is applied and theoretically when it is left outside to the sun over some time. The total weight of the panel is 3.2kg.





10

Business model



10.1 Introduction

At this juncture, it is evident that a plastic building component for temporary settlements can be designed and produced with a simple technological process. The strength of the material is comparable to what is presently being used in the camp but, it is a more robust system that allows for longevity. For the system to become a reality, the local people have to be taught how to produce it. This involves setting up a production line, determining the collection point, those responsible for the production, and the end of life of the plastics in general. This chapter will elaborate on all the aspects that are required to make this a feasible project. Three main questions will be tackled within this chapter.

How can this product be part of the recycling market in Nigeria?

What prospective production line can be set up to stimulate the local economy, starting with the IDP camp?

What are the long-term developments and or benefits?

10.2 The plastic building component in the Nigerian waste cycle

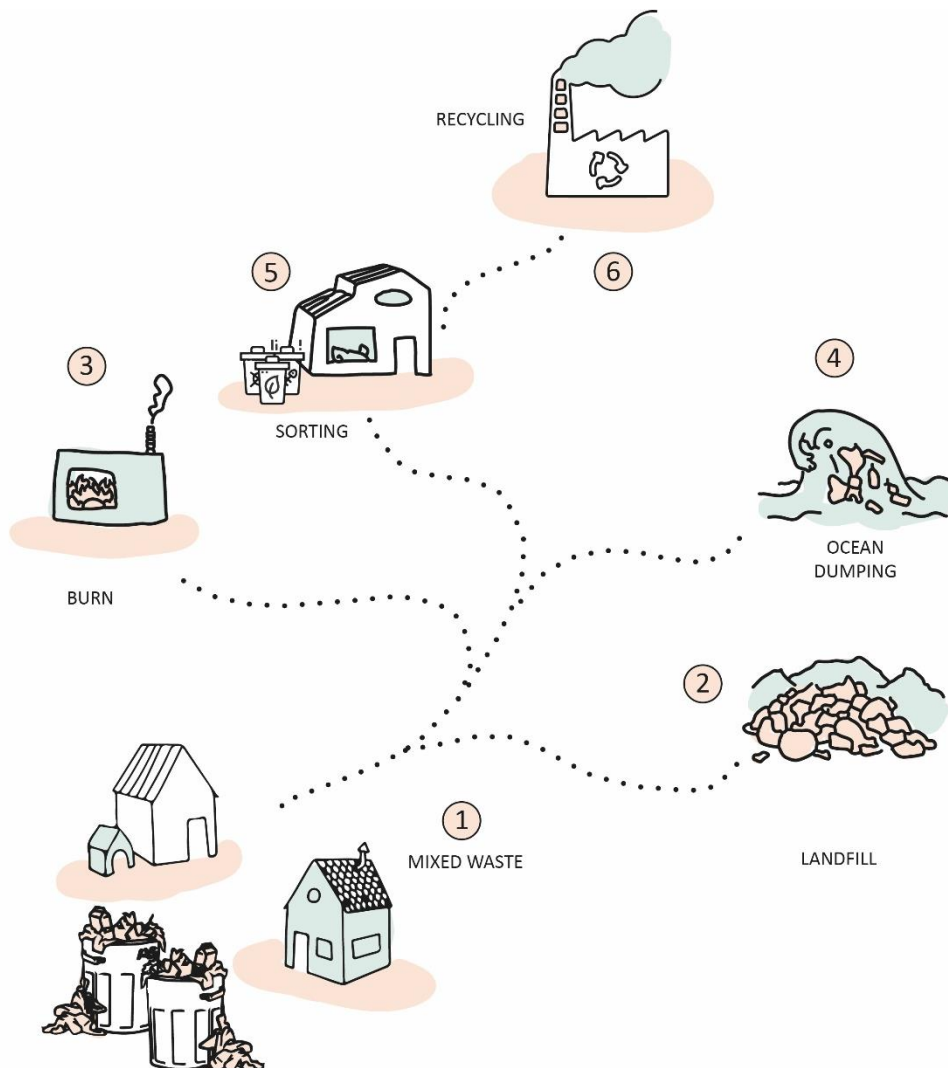


Figure 138: Existing waste disposal stream in Abuja

Human beings generally generate a large amount of plastic used for a short time before being discarded. The research conducted earlier in chapter 5 shows the statistics of plastic consumption is pretty high, while the recycling percentage is meagre. The plastics generally end up in three ways, as landfill, in the ocean, or incinerated, with a small portion going to recycling

The building component has the potential to enter this recycle stream in multiple ways, including:

- Collection:

Collecting the plastic is an essential step of secondary recycling. In order to transform PET, HPDE and LDPE into the building components, it is necessary to sort them into their various categories. The PET bottles come in different shapes and sizes and should be categorized as such. The bags need to be shredded; thus, they should also be separated from the bottles, but they do not need further separation as they are shredded together for use as insulation.

After separation, the plastic will be washed with only water to remove impurities. Seeing as moisture is also a contaminant in plastic processing, it should also be dried before use. The plastic collection works by putting a designated plastic collection point in different regions. Abuja, for example, has a lot of residential estates. A lot of them are located close to IDP camps. Once awareness is generated for this, people will begin to donate their single-use plastic bottles and bags. It can become an activity that brings the communities together. It can also be a way to earn money. Once a production line is set up, people can get paid for bringing plastic in for recycling into building components.

- Local production line:

A local factory can be established for the creation of composite plastic wall panels. This factory does not require much energy to be run and employs local labourers. The plastic collected from the collection centres are transported here, the supply will increase over time as people realise the importance and awareness is generated. The set-up will include a weaving area, an ironing area and a carpentry area. This production line can also accept old panels for repair and sells screws and all the materials required to set up a bacha. By doing this, a small self-sufficient economy is established. The camp is also kept neat as value is now added to waste. People can earn money by working at the line or by bringing in plastic.

- Housing:

The panels are either used to create a new bacha entirely or used with already existing buildings. Bachas are constantly being maintained or extended due to increased family size; the panels can be suitable for various functions and are easily adapted to suit different requirements.

- Re-enter the cycle:

The building component was designed with the end in mind as it is a temporary solution to a housing problem. Once the panels are weathered and used for two years, the plastic pieces can be detached. The screws are recyclable, and wood is biodegradable. The plastic can be collected and taken to organizations that collect waste plastic and shred them to re-enter the recycling circuit. These organizations pay for the plastic; thus, the owner of the panels can receive some income once the panels are no longer suitable.

10.3 Production line

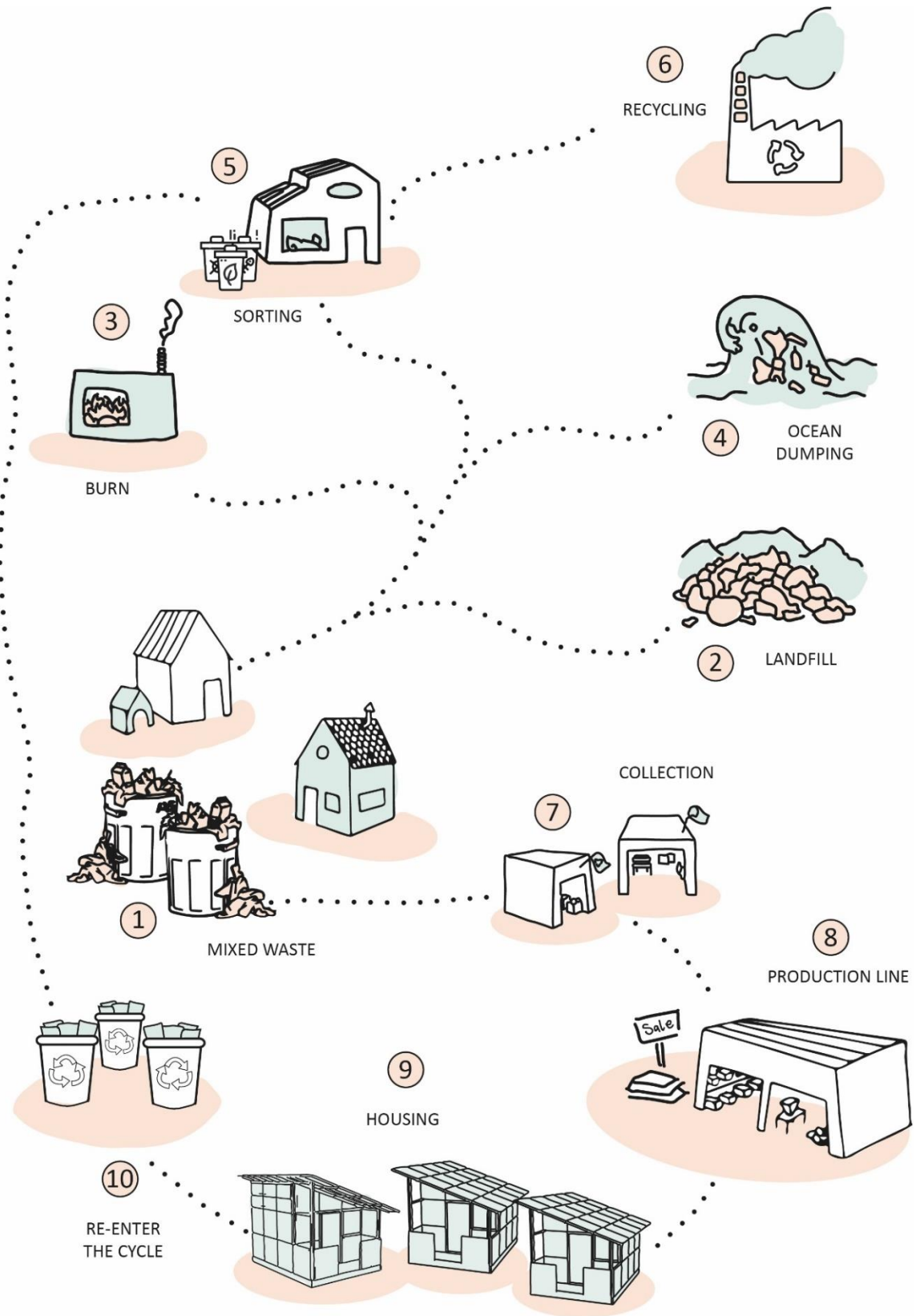


Figure 139: Waste stream with the plastic building system implemented

The set-up for the plastic component production line factory depends on numerous contextual variables. A potential system for a small plastic panel factory will be determined based on site analysis experience. The proposed factory set-up is based on the following production steps as derived from chapter 8 and 9. The first step to establishing the factory is to know the areas required.

1. Workspace

To guarantee safety within the camp outside office hours, it is crucial to have a storage space with a lock where all the materials can be kept under lock and key. It should also be large enough to house the activities of the production line. The workspace can be made out of wood and zinc, currently used at the IDP camp for communal areas. However, as plastic is being produced over time, it can also be made from plastic building components.

2. Washing or cleaning area

There should be a small area with basins that can be used for washing, cleaning and drying. This can be done outside as it involves water, and the sun is needed.

3. Sorting area

This is where the plastic materials are brought in. Ideally, it should be close to the entrance as it starts the chain of the production line. The plastic bottles are to be sorted by colour and size, while the shopping bags can be taken to be shredded directly.

4. Weaving area

This area will be where the people in the camp can learn how to weave themselves. There should be enough space for people to sit and a table for the PET thread to be produced. People can be employed to teach or weave plastic panels for a living.

5. Ironing area

This space requires at least a 1.2x1.2 table to enable the pressing and ironing of finished plastic pieces.

6. Carpentry area

This space will be for the cutting of the wood and the attachment of the panels accordingly. There should also be enough space to store any needed materials, e.g., cement bags, wood, nails, and so on

7. Storage area

This space will store materials required to build the bacha, including nails, produced panels, wood pieces and cement bags.

8. Plastic disposal area

This area is where the plastic panels which are no longer useable are disposed of. The plastic can be sold to the recycling initiatives such as Changa Datti mentioned earlier in chapter 6 in exchange for additional income.

Although the factory set-up is there to standardize panel creation and ensure continuous supply, people can also make the panels independently within their own families or homes. In so doing, the community bonds between the residents are strengthened, and the panel cost would even be less. The family as a whole can gather bottles and weave together, dividing the tasks between one another.

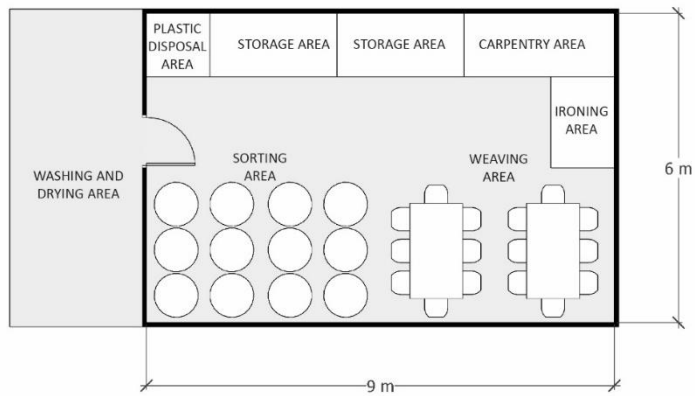


Figure 141: Production line plan

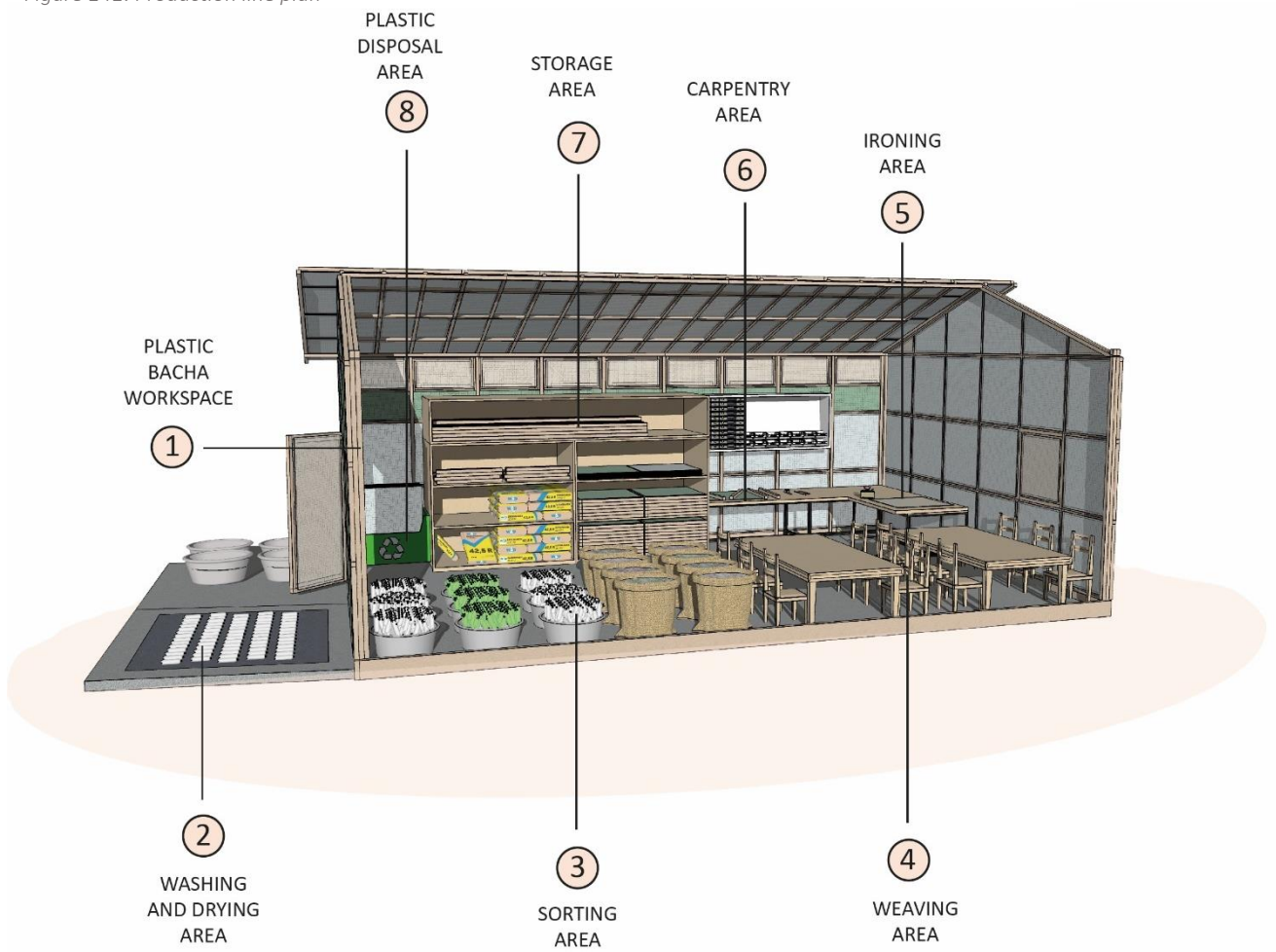


Figure 140: Production line

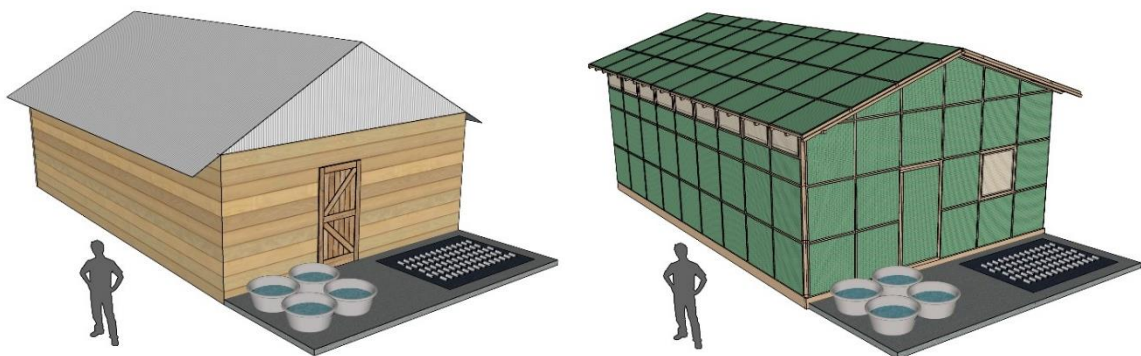


Figure 142: Workspace before and after panel production



Figure 143: Impression of people weaving panels together



Figure 144: Plastic accommodations in the camp

10.4 Long term development

The production line can potentially be scaled up so far as there is a demand for temporary housing and a plastic waste problem. The informal nature of the production is not designed as a high scale operation but rather one that serves the community at a local economic level. A factory like this requires some external capital investment to get the ball rolling. The start-up capital can be obtained from campaigns, NGO's or governmental institutions. Once one workshop is set up within the camp, there may be a demand in other camps, that requires expansion of the industry. Instead of increasing the set-up size, one production line can be set up in each IDP camp. The market can thrive within the local boundaries as long as it is not in direct competition with other big companies or industries. This will also help with the plastic or waste clean-up in different areas of the country.

It is essential to know that the market that this design is serving is a temporary housing market. The workshop set-up takes this into account; thus, it is easy to replicate anywhere. The small-scale business model's direct environmental and social effect must be tested in reality for a complete understanding of the overall benefits. However, the amount of waste decrease this can help to bring about can be estimated by making certain assumptions.

If the Abuja district of Kaura is considered, a population of about 50,000 people can be estimated as it is a region with many gated communities and families. An average of five people per household is estimated to amount to about 12 bottles a week per household and 15 shopping bags. For 10,000 homes, that means an average of 120,000 bottles and 150,000 shopping bags is estimated per week. This is enough to build 3.2 plastic bacha's a week and about 116.4 a year. Although this is an estimate, it shows that there is immense potential in reusing waste plastic. This calculation is visible in the appendix. It can be used as part of promotional incentives for people to recycle more and can be offered as an open-source document easily accessed online.

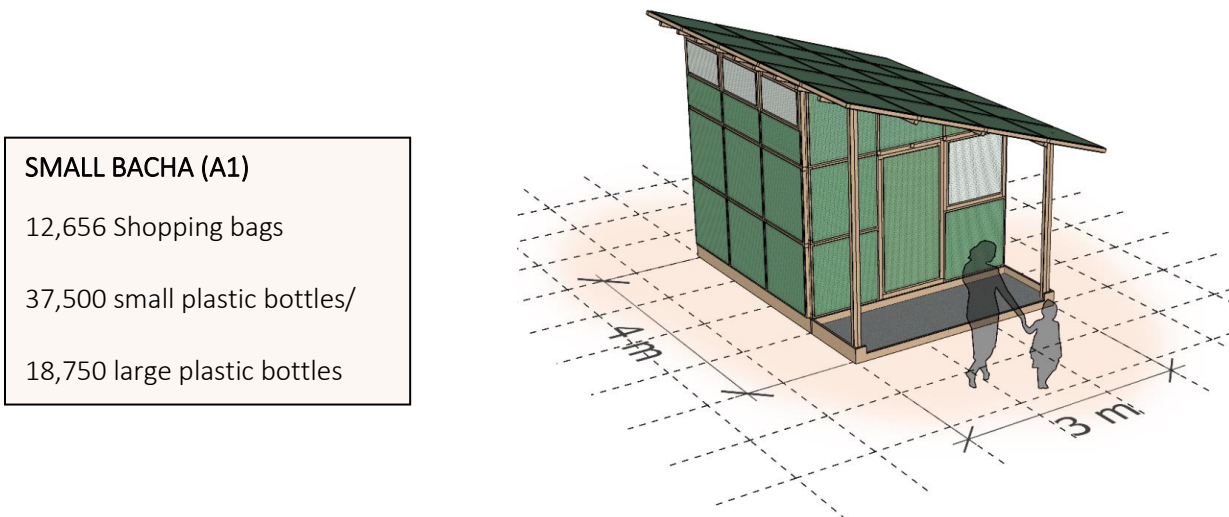


Figure 145: Bacha bottle number calculation

Based on the on-site analysis and literature research, the cost breakdown of the panel is estimated to cost around NGN350 (EUR0.70) per panel. Although theoretically, the plastic is meant to be free as it is waste plastic, a cost has to be assigned to it to reflect transportation and cleaning.

	Amount	Cost (NGN)	Total
PET panel	2	25	50
Wood	4	50	200
HDPE bags	200	0.5	100
TOTAL			350

Table 14: Panel price calculation

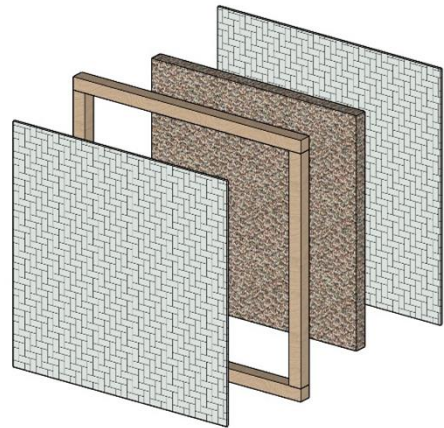


Figure 146: Panel configuration

Once the cost of one panel has been estimated, the total cost of building one bacha also needs to be determined. This involves the cost of all the different parts that make up the system, including the wooden base panels, the wooden columns/bars and the concrete, although that is optional.

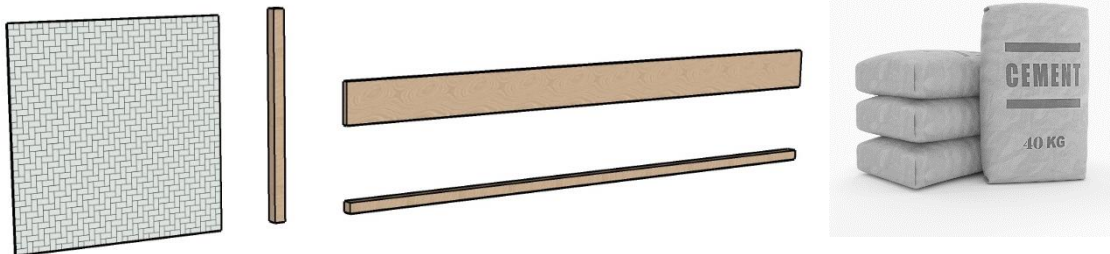


Figure 147: Bacha building materials

Building part	Amount	Cost (NGN)	Total cost (NGN)
Wooden bars	42	250	10500
Bottom wood panels	4	500	2000
Composite panel			
PET	50	50	2500
Wood frame	50	250	12500
Shopping bag	50	50	2500
Total			30000

Table 15: Bacha A1 building cost calculation

The basic bacha cost is NGN30,000 (60.13 EUR). The base can be built with wood. If the residents have enough money to use concrete, the total comes up to NGN49,200 (EUR98.59).

Building part	Amount	Cost (NGN)	Total cost (NGN)
Cost of the panel and other parts			30000
Concrete	8	2400	19200
Total			49200

Table 16: Bacha building cost calculation including concrete base

The total cost of the bacha is about twice what the residents pay now if they want to have the basic unit, including the concrete base. As an incentive, the residents need to know that it is worth it, and income can be gained from the plastics at the end of life. Using the estimate of NGN 50 (EUR 0.10) per kg for the recyclable plastic, the panel worth at the end of life can be calculated as follows:

End of life	Amount	Weight	Cost	Total cost
One panel PET	2	11.25	50	562.50
HDPE	200	2.35	50	117.70
PET cut off	375	3.8	50	187.5
Total price for one panel	1			867.7
Total price for one bacha (50 panels)	50			43385

Table 17: The selling price of the plastic used to make the bacha at the end of life

So, in theory, residents can pay NGN350 (EUR0.70) to build their component and sell it at the end of life for NGN 867.70 (EUR 1.77). In the long term, the house pays for itself. However, this is a theoretical assumption and will need to be applied in practice over a period of time to test its efficacy.

There are other benefits to the design of this system apart from recycling and the economic benefits: the design solution is a building component and a whole system that also includes the production line. The system is made relatively simple and easy to follow for two main reasons: making it easy to understand and build, making it adaptable and easily improved upon. Over time once the system is used, the end-users can make adjustments to the design as they see fit. People in temporary shelters often find inventive and new ways to reuse materials; therefore, it is expected that they will find methods in which the design can be improved. The improvement is not only for the building component itself but for the production line and the housing in general. Therefore, the proposal should not be taken as a finalized method but one that can be optimized and is open to further adjustments and improvements.

12

Conclusion



11.1 Conclusion

The general objective of this research is to improve the living conditions of an IDP camp called Kuchingoro, located within the Federal Capital Territory (Abuja), Nigeria, by making a building component out of plastic waste. The literature research and on-site analysis culminated in the formation of a design brief in chapter 7, which subsequently informed the component's design and an overall system.

The design brief set out some clear objectives to achieve in the design, and this will be the guideline to determine if the research was successful at accomplishing the goals. According to the design brief, the building component should be a repetitive module that can be used as a structural or cladding material and form a large portion of the building envelope. The design of the building component is an insulated panel made out of PET, wood and shredded LDPE. This component is designed to be attached to a wooden frame. Each panel is 1x1m to ensure it complies with the grid of the building. The material content of the panel is made up of 69% PET, 27% LDPE and 4% wood. The raw materials are derived from plastic bottles, both coloured and clear, shopping bags and pure water sachets.

The production line of the building system can currently fit into existing communal halls within the camp, with the intention to expand once the panels start being produced. The production process is also very low tech; it involves manual weaving, sorting, pressing and basic carpentry. This low-tech nature ensures that the residents can produce it with only a little investment.

The building method used is identifiable with the technique presently used in the camp. It is incremental in nature and takes into consideration the different family types. Different housing typologies are developed with different family types in mind. Screws are also used to connect the panels to the frame, so it's easily demountable.

The panel has not been tested for durability against the Nigerian climate; this is especially important as manually woven materials are prone to water seeping through it. According to the testing, the tighter the weave is, the less prone to water leakage. Theoretically, based on past research, PET can last for up to two years, with the tensile strength decreased by about 12%-28%. It is also thicker and more rigid than the polypropylene fabric being used now. The panel will have to be implemented in reality to adequately test the durability for the future development of the building system.

The Rc value of the component is 0.432 m²K.W. This is comparable to a concrete wall of 0.45m²K.W and polypropylene, which is around 0.21 m²K.W. This is undoubtedly an improvement from what is used now.

The component is 1m x 1m and weighs approximately 19kg. This can be carried by two people and stacked repeatedly. The grid also ensures that a door of around 1.8m and windows of 0.8m x 0.8m can be placed. The building system ensures that the components have as little variation as possible, all the wooden pieces are 50mm thick, and all the panels are 950mm wide. This makes it easier to build.

The tensile strength of the component was tested, and it is comparable to that of two polypropylene bags being used in the camp. In terms of rigidity, it is more sturdy and stiffer than polypropylene. This will make it difficult for animals like rats, insects or the weather to damage it.

The bacha is around NGN30,000 (60.13 EUR) for a basic bacha and NGN49,200 (EUR98.59), including the concrete base in terms of cost. This is currently more expensive than what is being used now. A selling scheme for the plastic at the end of life puts the worth of the plastic parts at around NGN43,385 (EUR88.58). In the long term, the revenue generated from recycling can cater for the cost of the bacha. Furthermore, the camp residents stated that they would not mind a more expensive component if it lasts longer.

Throughout this research, care was taken to ensure feasibility by sticking to the design brief as much as possible. It is important to note that this report serves as a means to inspire further development. The content should be considered an ideal development that is open to improvement and not a finalised product. Additional investments into this research field could potentially solve the problem of temporary housing and adequate plastic management.

11.2 Recommendations

Several topics can be explored in further research.

In chapter 8: Material design, the material was explored at the level of only a small prototype, and the only testing carried out was for the tensile strength. However, for a complete understanding of the properties of recycled plastic, further research is needed. Structural analysis regarding the façade panel and the connection to the frame would also prove helpful and give additional insights into the overall panel's mechanical properties. Water testing needs to be done to determine how suitable the material is against water invasion. Another improvement can be the weaving technique itself. It may be possible to standardize the process by taking it a step further. Fire testing can also prove helpful to ensure safety; fire-retardant additives can be added and tested in this case.

In chapter 9: Architectural application, a building system was developed for the building component. This design is open to further analysis and changes to make it more energy-efficient and sustainable. These changes can include the addition of solar panels or rain-water collectors. Furthermore, the design itself can be adjusted accordingly until it suits the need of the end-users. The climate strategy employed can also be further explored regarding energy gain and loss by using design-builder for more in-depth analysis.

Chapter 10: The business model makes a case for the economic benefits of this system. This is very theoretical with estimated numbers. A proper business plan needs to be generated to get more exact facts and figures to ensure that the plastic component can compete with the materials in the camp, like polypropylene and zinc. The production line can also be improved upon by speaking to the camp residents. They know what works best, so it is expected that some changes may occur if it is being implemented.

Unfortunately, plastic waste is found all over the country; therefore, the production line can prove helpful in the long term. Communities can keep surroundings clean and build structures that have an end of life clearly mapped out. By doing this, jobs and the health of people are improved immensely. Thus, the production line will need to be mapped out clearly, and the documents should be open sourced entirely and available to the public.

11.3 Personal reflection

This chapter will be used to reflect on the relationship between planning and the development of a product. The graduation topic “Recycling plastic waste into a low-cost building component for internally displaced persons (IDP) camp resettlement housing in Nigeria” is within the building technology studio’s façade and products design aspect. This is concerned with the investigation of typologies, materialisation and fabrication of a façade system and product.

In Chapter 1, the research definition is made; this includes a process scheme and a schedule. However, the realisation of a final product is not as linear a process as the theory.

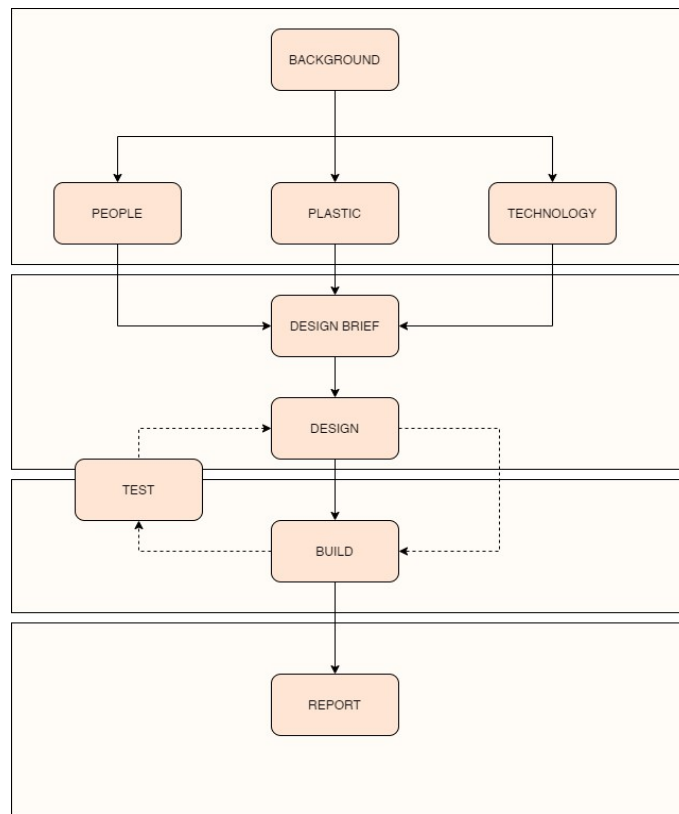


Figure 148: Research plan

The research project is driven by a social problem in Nigeria. Internally Displaced Persons in Nigeria do not have suitable building materials when forced to flee to other states. This problem is explored through literature research in Chapter 2: “Towards Understanding a foreign background”. The main issue discussed within this chapter is the recent war occurring in the Northeast, which has caused a migration problem and the government not handling the situation appropriately. The IDP’s are not recognised officially as refugees; therefore, they are not afforded adequate or sustainable housing opportunities. This lack of recognition leaves them ultimately to fend for themselves, and the only housing typologies available are not in line with the official UNHCR standards. This problem is quite complex, and after a site visit to the camp during a holiday break in Nigeria, a few other things had to be considered. During the research process, a “design brief” is used to set up a guideline to produce a viable product that can be created and used within the context of Kuchingoro Camp in Abuja, Nigeria. The reflection can critically explore the conceptual design and physical results of the building components. The final goal will be to determine how much improvement is required to become feasible in the real world and how valuable it is for the end-users. If it requires modification, the evaluation will help determine

where there is a failure in the design brief or the process of design itself. So far, the research approach is beneficial because it can guide the process to benefit the end-user and the feasibility. At the end of the project, certain assumptions have to be made to prove its applicability in a real-life context.

- **How are research and design related?**

Research and design go hand in hand in creating a product for a specific demographic and within a particular context. For this study, the main aim was to create a design brief based on research to solve the existing problem of both plastic waste and housing problems simultaneously. The design brief is a culmination of the findings of the literature review and site visit. It was made after stage one, as shown in figure 1. The results of the literature findings gave an initial estimation of a problem and a solution that seems most plausible at the time was plastic bricks. This is because it is a form of construction that is native to the camp residents and familiar within Abuja and Nigeria as a whole. Upon further investigation into the camps living conditions, I was surprised to find that the central problem they faced with their housing was the collection of water within the shacks (bacha). Upon further interviews, the residents do not mind changing the bacha's every year or two, but they worry about water collection due to the nature of the materials they use now. It was most surprising to hear that zinc plated sheets are considered a more high-class material because it is stiffer and less prone to collecting water like the plastic sheets/tarpaulin they use now. This realisation led to a conclusion that differed from the initial idea of bricks. In addition to this, the construction process for plastic bricks is a lot more complicated and cost-intensive; if this project is feasible, the economic implications would also have to be considered. A combination of all these factors led to the development of a project which could involve multiple members of the camp in all the processes (weaving, sheet pressing, and building)

The research, however, did not end at this point; the approach of 'design by research' is transformed into 'research by design. This approach infers that after creating the design brief, a set-up needs to be constructed to develop the product and possibly test it. This process is referred to as 'learning by doing'. The solution required needs to be built by unskilled labour, and what better way to ensure its validity by building and testing by oneself. The evaluation chapter can critically analyse this approach of 'learning by doing' to determine its improvement and value.

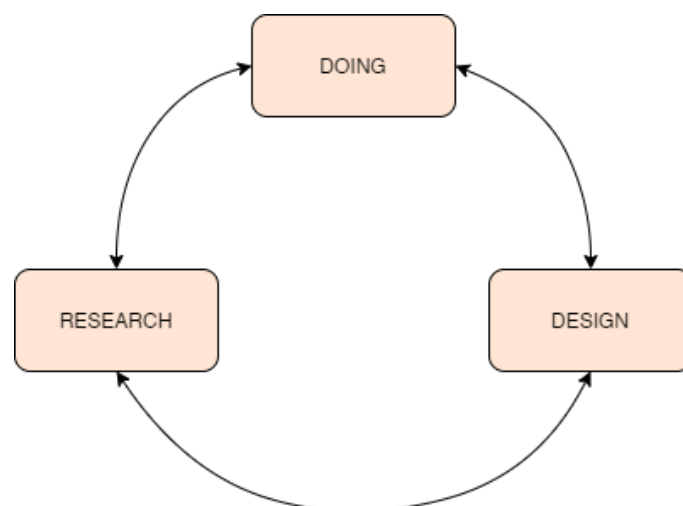


Figure 149: Relationship between research, doing and design

This process of research and then designing shows that the desires of the end-users are most important. The most complicated solutions are usually very cost-intensive, and it is essential to keep things as simple as possible

in a context of low economic power. To ensure that the project is feasible, the research also helped determine the type of plastic most suitable for this climate based on availability, material properties, and skill set of the people within the camp. From this, it is inferred that recycling PET bottles into thread can be woven into plastic sheets to replace the zinc sheets and tarpaulin currently used in the camp. The final design shows that the weaving technique affects the design quite significantly. The strength of the overall weave is also improved when the weave itself is as tight as possible. The strength can withstand almost 1000 N of force and is comparable to four times the thickness of the material used in the camp now.

SOCIETAL IMPACT

- *To what extent are the results applicable in practice?*

The set-up for the prototypes so far is all produced with readily available materials. Plastic water bottles are also used as they are one of the significant sources of plastic waste. Insulation is made from shredded HDPE and LDPE shopping bags. In this way, various plastic types are utilised. The methods used are more labour intensive; therefore, they may take longer; however, for the context, this is not an issue as labour is abundant. Thus, in practice, the methods used should be achievable.

- *To what extent has the projected innovation been achieved?*

According to the literature research, the primary building components made out of recycled plastic are bricks or solid HDPE type sheets. Most of the precedents are used with the plastic shredded and cut down, melted and then moulded into a specific shape. This project takes a different approach entirely, where materials are manually woven and pressed to produce a plastic sheet. The weaving process is not foreign to the context of Nigeria; however, using this technique for a building product is not something that has been achieved. Although the combination of methods used to create the product is innovative, further testing will determine whether the projected innovation has been achieved.

- Does the project contribute to sustainable development?

Humans have created a consumption-driven system that creates a divide between very low-income earners and society. Thus, the housing systems used in these camps are of the lowest quality. Another problem facing the country is plastic waste. This is a global problem that is particularly evident within Nigeria. Without a proper large scale waste management system, the plastic ends up in water bodies or landfills and contributes to environmental degradation. Therefore, strategies for recycling plastic effectively and efficiently need to be developed. This research aims to provide a possible solution for both issues, thus providing economical and environmentally sustainable development in the long term.

- *What is the socio-cultural and ethical impact?*

According to the statistics found when doing the literature review, plastic is widely used within Nigeria. There are some initiatives towards recycling plastic into plastic bricks, clothes, bags, shoes and other materials. The more initiatives like this come forward, the more awareness is created for a rapidly increasing problem every year. Within the camp itself, plastic waste is burnt or thrown away; this would provide an incentive for reuse within that community of over 1000 people. From an ethical point of view, it could drastically improve the lives of people who reside within these camps. The fundamental human rights are access to food, water, and shelter; this proposal will help generate shelter and economic opportunities to satisfy the other two needs.

- *How does the project affect architecture / the built environment?*

As climate change rapidly progresses, there is an increasing need to develop solutions that use our already existing resources to create new ones. This project employs a methodology and system that uses traditional skills and plastic waste to create a new product. If this form of thinking could be applied worldwide, many green buildings with reduced carbon footprints would be created.

REFERENCES

1. Abbakari, M and Taki, A. *Passive Design Strategies for Energy-Efficient Housing in Nigeria*. Retrieved 11 January 2021, from https://www.researchgate.net/publication/320673556_Passive_Design_Strategies_for_Energy_Efficient_Housing_in_Nigeria
2. Abuja city profile. (2014). *Cities*, 41, 81–91. <https://doi.org/10.1016/j.cities.2014.05.008>
3. Aloba, A., Adebowale, A. (2020, February 8). *Drone Story: Inside Abuja’s ‘unauthorised’ IDP camps*. Premium times. <https://www.premiumtimesng.com/news/headlines/375876-drone-story-inside-abujas-unauthorised-idp-camps.html>
4. Aljoumaa, K., & Abboudi, M. (2015). Physical ageing of polyethylene terephthalate under natural sunlight: correlation study between crystallinity and mechanical properties. *Appl. Phys. A (2016) 122:6*. DOI 10.1007/s00339-015-9518-0
5. Amanchukwu, R. N. et al. (2015). Climate change education in Nigeria: The role of curriculum review. *Education*, 5(3): 71-79. https://www.researchgate.net/profile/Nwachukwu_Prince_Ololube/publication/2830817
6. Amina, B. Z. J., & Ibrahim, S. G. (2019). *The Plight of Internally Displaced Persons in Unofficial Camps in The Federal Capital Territory of Nigeria, Abuja*. 2(3), 11.
7. Akinradewo, O. F., & Adedokun, D. O. (2020). Comparative Cost Analysis of using Conventional Blocks and Interlocking Bricks for Mass Housing in Nigeria. *Covenant Journal of Research in the Built Environment*, 8(1). <https://doi.org/10.47231/WXGY9716>
8. African clean cities.org. (2018). *Nigeria, Abuja*. https://africancleancities.org/assets/data/Organization/Abuja_EN.pdf
9. 78_Climate_Change_Education_in_Nigeria_The_Role_of_Curriculum_Review/links/56292c5508ae518e347c967b/Climate-Change-Education-in-Nigeria-The-Role-of-Curriculum-Review.pdf
10. Arup (Madrid & Lagos offices), (2016) *Building Energy Efficiency Guideline for Nigeria*. Federal Ministry of Power, Works and Housing (Housing). Retrieved June 19, 2021, from https://energypedia.info/images/c/c7/Building_Energy_Efficiency_Guideline_for_Nigeria_2016.pdf
11. Askeland, D.R. “Mechanical Testing and Properties.” *The Science and Engineering of Materials*. London: Chapman & Hall, 1988. 5th Edition at www.ius.edu.ba/csarioglu/ENS205/ch6.pdf
12. Awoyera, P.O., Ndambuki, J.M., Akinmusuru, J.O., & Omole, D. O. (2016). Characterization of ceramic waste aggregate concrete, *HBRC J.* 14 (3) (2016) 282–287, doi: <http://dx.doi.org/10.1016/j.hbrj.2016.11.003>.
13. Babayemi, J., & Dauda, K. (2009). Evaluation of solid waste generation, categories and disposal options in developing countries: a case study of Nigeria. *J Appl Sci Environ Manag*; 13(3):83e8
14. Babayemi J.O., Ogundiran M.B., Weber R., Osibanjo O. (2018). Initial inventory of plastics imports in Nigeria as a basis for more sustainable management policies. *J. Health Pollut*; 8(18)
15. Babayemi, J.O., Nnorom, I.C., Osibanjo, O. et al. (2019). Ensuring sustainability in plastics use in Africa: consumption, waste generation, and projections. *Environ Sci Eur* 31, 60. <https://doi.org/10.1186/s12302-019-0254-5>
16. Building component. (n.d.) *McGraw-Hill Dictionary of Architecture and Construction*. (2003). Retrieved January 6 2021 from <https://encyclopedia2.thefreedictionary.com/Building+component>
17. Cairns Regional Council (2011). ‘Sustainable Tropical Building Design: Guidelines for Commercial Buildings’ Retrieved 10 January 2021 from http://www.cairns.qld.gov.au/_data/assets/pdf_file/0003/45642/BuildingDesign.pdf
18. Caux, H. (2013). *Under the radar: Internally displaced persons in non-camp settings*. Brookings, OR: United Nations High Commissioner for Refugee.

19. Chaisupakitsin, M., Chairat-utai, P., & Jarusiripot, C. (2019). Degradation of polyethylene terephthalate bottles after long sunlight exposure. Retrieved 12 April, 2021 from <https://rdo.psu.ac.th/sjstweb/journal/41-2/2.pdf>
20. (21) (PDF) *Insurgency and the Invisible Displaced Population in Nigeria: A Situational Analysis*. Retrieved 9 January 2021, from https://www.researchgate.net/publication/332728698_Insurgency_and_the_Invisible_Displaced_Population_in_Nigeria_A_Situational_Analysis [accessed Jan 09 2021].
21. Chintuo, A. G., & Egolum, C. C. (2020). *Examination of Challenges in the Provision and Management of Facilities in Selected Internally Displaced Persons Camp in Abuja*. 3(8), 12.
22. Climate-Data.org. (n.d.). *Abuja climate: Average Temperature, weather by month, Abuja weather averages*. Retrieved 9 January 2021, from <https://en.climate-data.org/africa/nigeria/federal-capital-territory/abuja-703/>
23. City population.de. (2020). *(Federal Capital Territory (Nigeria) - Population Statistics, Charts, Map and Location, 2020.)* Retrieved 27 December, 2020 from <https://www.citypopulation.de/php/nigeria-admin.php?adm1id=NGA015>
24. Cohen, R. & Deng, F.M. (1998). Exodus within borders: The uprooted who never left Home, *Journal of Foreign Affairs*, 77(4), 12-16.
25. Dennison, G.J., Dodd, V.A., Whelan, B. (1996). A socio-economic based survey of household waste characteristics in the city of Dublin, Ireland - II. Waste quantities. *J. Resources, Conservation and Recycling*; 17(3) 245-257
26. IDM Nigeria (2016). *Displacement Tracking Matrix* (Round 11 report). DTM. <https://dtm.iom.int/nigeria>
27. Edem-Nse. Y. G, Muhammad. I. B & Momoh. S. A. (2017). *User's Cultural Specific Spatial Needs in the Internally Displaced Persons (IDP) Camps in Abuja, Nigeria*. Research Gate. Retrieved 6 January 2021, from https://www.researchgate.net/publication/322700312_User's_Cultural_Specific_Spatial_Needs_in_the_Internally_Displaced_Persons_IDP_Camps_in_Abuja_Nigeria
28. Edoga M, Onyeji L, Oguntosin O. (2008). Achieving vision 20: 2020 through waste produce candle. *J Eng Appl Sci*; 3(8):642e6.
29. Engineering For Change | By Engineers, For Everyone. (2020). Retrieved 12 January 2021, from <https://www.engineeringforchange.org/>
30. Enwerekowe, E., & Ibrahim, S. (2019). *The Effect of IDP Camps on Urban Environmental Degradation: A Study in North Central Nigeria*. Retrieved December 20, 2020, from https://www.researchgate.net/publication/344886874_The_Effect_of_IDP_Camps_on_Urban_Environmental_Degradation_A_Study_in_North_Central_Nigeria
31. Haider, H. (2019). *Climate change in Nigeria: Impacts and responses*. 38. Retrieved 9 January 2021, from <https://www.preventionweb.net/publications/view/68975>
32. Handbook for the protection of internally displaced persons. (2010). Afghanistan Centre at Kabul University. https://doi.org/10.29171/azu_acku_hv555_a3_h363_2010
33. Household Cooking Energy Situation in Nigeria: Insight from Nigeria Malaria Indicator Survey. (2015). Retrieved 9 January 2021, from https://www.researchgate.net/publication/328688775_Household_Cooking_Energy_Situation_in_Nigeria_Insight_from_Nigeria_Malaria_Indicator_Survey_2015
34. IDP definition—UNHCR|Emergency Handbook. (n.d.). Retrieved 8 December 2020, from <https://emergency.unhcr.org/entry/44826/idp-definition>.
35. IDMC (Internal Displacement Monitoring centre). (2020). *NIGERIA*. Retrieved December 11, 2020, from <https://www.internal-displacement.org/countries/nigeria>

36. Ike C, Ezeibe C, Anijiofor S, Daud N. (2018). Solid waste management in Nigeria: problems, prospects, and policies. *J Solid Waste Technol Manag*; 44(2):163e72.
37. Ishaku, J. et al. (2020). *Building the Resilience of Internally Displaced Persons in Nigeria*. CSEA- Centre for the Study of the Economies of Africa Report. <http://cseaafrica.org/wpcontent/uploads/2020/02/Building-the-Resilience-of-Internally-Displaced-persons-in-Nigeria.pdf>
38. Imam, A., Mohammed, B., Wilson D.C., Cheeseman, C.R. (2008). Solid waste management in Abuja, Nigeria. *Waste Manag*; 28(2):468e72.
39. Imasuen, E. (2015). Insurgency and humanitarian crises in Northern Nigeria: The case of Boko Haram. *African Journal of Political Science and International Relations*, 9, 284-296. (21) (PDF) *Insurgency and the Invisible Displaced Population in Nigeria: A Situational Analysis*. Available from: https://www.researchgate.net/publication/332728698_Insurgency_and_the_Invisible_Displaced_Population_in_Nigeria_A_Situational_Analysis [accessed Jan 09 2021].
40. Kusimo, O. (2019) Findings from a Windshield Survey Conducted in an Internally Displaced Community in Nigeria. *Health*, 11, 50-56. doi: [10.4236/health.2019.111006](https://doi.org/10.4236/health.2019.111006).
41. Lechner, N. (2014). *Heating, cooling, lighting: Sustainable design methods for architects*. John Wiley & sons. Retrieved 2 January 2020 from https://www.researchgate.net/publication/320673556_Passive_Design_Strategies_for_Energy_Efficient_Housing_in_Nigeria
42. Levinus, N. (2015). "Abuja Area One IDPs camp: A place of tears uncertainty". Vanguard Newspaper. Retrieved 27 December 2020 from <https://www.vanguardngr.com/2015/03/abuja-area-one-idps-camp-a-place-of-tearsuncertainty/>
43. Livingcost.org. (2020). *Prices in the Netherlands vs Nigeria - Cost of Living Comparison*. <https://livingcost.org/cost/netherlands/nigeria>
44. Megbowon, E., & Mukarumbwa, P. & , Ojo, S. (2015). Household Cooking Energy Situation in Nigeria: Insight from Nigeria Malaria Indicator Survey 2015. *International Journal of Energy Economics and Policy* 8(6):284-291. DOI: [10.32479/ijeeep.6913](https://doi.org/10.32479/ijeeep.6913)
45. Mercy Corps (2018). *LOCAL CONSTRUCTION PRACTICES & HOUSING TYPOLOGIES BORNO STATE, NIGERIA* (Draft_v005_). https://abjournals.org/african-journal-of-social-sciences-and-humanities-research-ajsshr/wp-content/uploads/sites/9/journal/published_paper/volume-2/issue-3/AJSSHR_jzxr2al0.pdf
46. Meteoblue weather (2021). *Climate Abuja*. Retrieved 8 January 2021, from https://www.meteoblue.com/en/weather/historyclimate/climatemodelled/abuja_nigeria_2352778
47. National Legislative Bodies / National Authorities (2012). *Nigeria: National Policy on Internally Displaced Persons, 2012*, retrieved from <https://www.refworld.org/docid/5a7ae2324.html> [accessed 6 January 2021]
48. National Population Commission. (2021). *Providing Demographic Data For Social and Economic Planning For National Development*. Retrieved 9 January 2021, from <https://www.nationalpopulation.gov.ng/>
49. *Nigeria Data Portal*. (2020). *State Population, 2006*. Retrieved 9 January 2021, from <https://nigeria.opendataforafrica.org/ifpxbd/state-population-2006>
50. Nguyen, Nguyen T., "A Conductivity Testing System Coupled with a Tensile Testing Machine to Measure the Surface Properties of Polymer Specimens" (2012). Mechanical (and Materials) Engineering -- Dissertations, Theses, and Student Research. 35. <https://digitalcommons.unl.edu/mechengdiss/35>

51. Nnaji CC, Eluwa C, Nwoji C. (2013). Dynamics of domestic water supply and consumption in a semi-urban Nigerian city. *Habitat Int*; 40:127e35.
52. Nnaji, C. C. (2014). Status of municipal solid waste generation and disposal in Nigeria. *Manag Environ Qual Int J*;26(1):53e71.
53. Obiadi, B. (2020). Architecture Of Cities And The Politics Of Abhorrence In Nigeria: A Case Of Political Neglect, Abandonment And Homelessness. *Advances in Social Sciences Research Journal*, 7, 218–236. <https://doi.org/10.14738/assrj.78.8744>
54. Ogwueleka, T. C. (2013). Survey of household waste composition and quantities in Abuja, Nigeria. *J Resources, Conservation and Recycling*; 77:52-60
55. Olanrewaju, F, et al. (2019). *Insurgency and the Invisible Displaced Population in Nigeria: A Situational Analysis*. ResearchGate. Retrieved 9 January 2021, from https://www.researchgate.net/publication/332728698_Insurgency_and_the_Invisible_Displaced_Population_in_Nigeria_A_Situational_Analysis
56. *Nigeria Population (2021)*—Worldometer. Retrieved 8 January 2021, from <https://www.worldometers.info/world-population/nigeria-population/>
57. Reuben, K. U et al. (2020). *Nigeria | History, Population, Flag, Map, Languages, Capital, & Facts*. Encyclopedia Britannica. <https://www.britannica.com/place/Nigeria>
58. Van den Berg, S. (2019). *Introducing a recycled building component: A first step towards sustainable and adequate informal housing in South Africa*. [Master's thesis, Delft University of Technology]. <http://resolver.tudelft.nl/uuid:029b1e67-d0a9-40f4-9afe-77cfebbc5a5d>
59. Sittrop, M. (2019). *Plastic Bamboo Connections Transform plastic waste into a useful tool for remote and low-income areas* [Master's thesis, Delft University of Technology]. <http://resolver.tudelft.nl/uuid:8fc1a20a-dda6-4332-9eaa-5a2953145aca>
60. Tong, T. (2017, November 30). *Afraid to Use the Toilet? These Women Are Vulnerable to Rape, Attacks While in Bathroom*. 11alive. <https://www.11alive.com/article/news/nationnow/afraid-to-use-the-toilet-these-women-are-vulnerable-to-rape-attacks-while-inbathroom/465-31ba7a31-6fda-4167-b11d-d5f45266ec2c>
61. Thomas, G. P. (2012). *Recycling of High-Density Polyethylene (HDPE or PEHD)*. Retrieved June 11, 2018, from <https://www.azocleantech.com/article.aspx?ArticleID=255>
62. Varrella, S. (2020). *Nigeria: Minimum wage 2018-2020*. Statista. Retrieved 9 January 2021, from <https://www.statista.com/statistics/1119133/monthly-minimum-wage-in-nigeria/>

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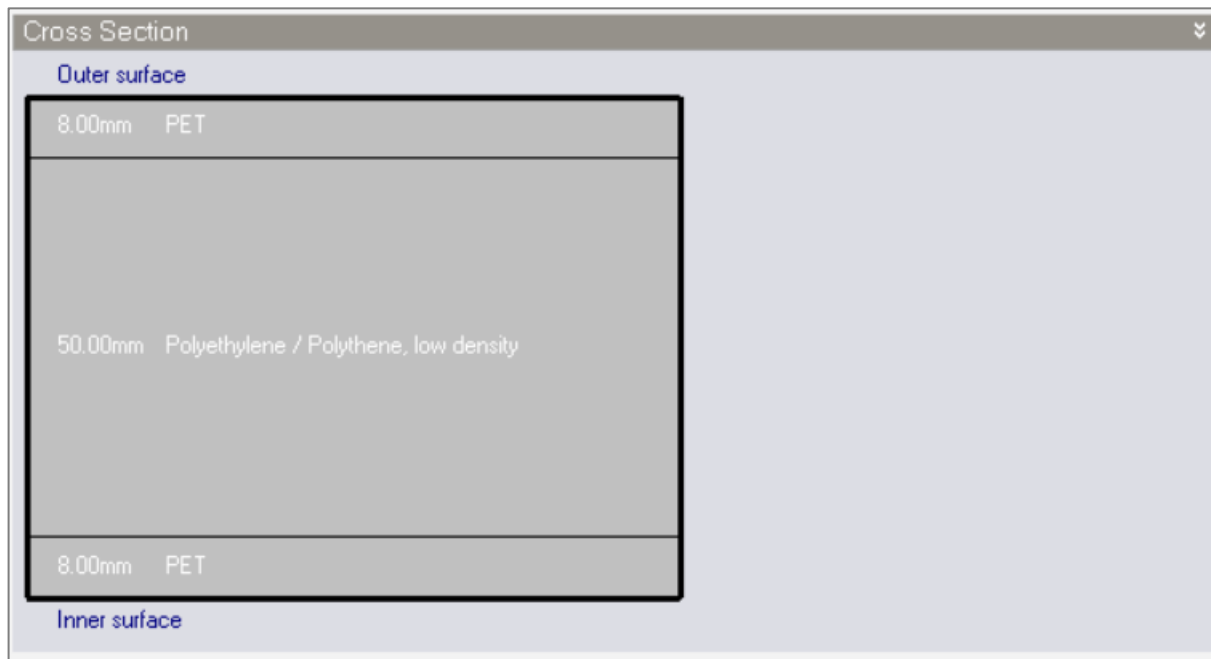
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APPENDIX I – Interview questions used in Kuchingoro IDP camp

- What is your name?
- What is your age?
- What year did you come to live in this camp?
- Are you married?
- What do you do for a living?
- How long does it take for you to get there?
- How much do you earn at your job, with and without your partner
- Where did you buy the materials used to build your house?
- How much did it cost to build your house?
- What is the major problem with your house?
- How long does your house last before it needs to be changed
- What is the most desirable material in the camp for building
- What do you do with waste materials in the camp?
- Does water bother your house during heavy rains?
- What do you do to prevent this from happening?
- Where do you usually cook?
- What are your primary concerns about living in Kuchingoro
- What do you like the most about your settlement?

APPENDIX II - Building component climate calculation with design-

Inner surface	
Convective heat transfer coefficient (W/m ² -K)	2.152
Radiative heat transfer coefficient (W/m ² -K)	5.540
Surface resistance (m ² -K/W)	0.130
Outer surface	
Convective heat transfer coefficient (W/m ² -K)	19.870
Radiative heat transfer coefficient (W/m ² -K)	5.130
Surface resistance (m ² -K/W)	0.040
No Bridging	
U-Value surface to surface (W/m ² -K)	3.819
R-Value (m ² -K/W)	0.432
U-Value (W/m²-K)	2.316
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.0660
Km - Internal heat capacity (KJ/m ² -K)	63.4640
Upper resistance limit (m ² -K/W)	0.432
Lower resistance limit (m ² -K/W)	0.432
U-Value surface to surface (W/m ² -K)	3.819
R-Value (m ² -K/W)	0.432
U-Value (W/m²-K)	2.316



builder software

APPENDIX III - Defining the required amount of PET bottles, wood and LDPE/HDPE plastic bags

TEST PANEL (0.4x 0.4)	Thickness (m)	Length (m)	Width (m)	Area (m2)	Volume (m3)	Count	Small Plastic bottles (0.5L)	Large Plastic bottles(1.5L)	Weight (kg)
PET	0.008	0.4	0.4	0.16	0.00128	1	60	30	0.9
Filling LDPE X HDPE	0.05	0.4	0.4	0.16	0.008	50			0.465
	0.05	0.3	0.05	0.015	0.00075	4			1.8
Total	0.108	1.1	0.85	0.335	0.01003	55	60	30	3.17

FULL SIZE PANEL	1	Thickness (m)	Length (m)	Width (m)	Area (m2)	Volume(m3)	Count	Small Plastic bottles (0.5L)	Large Plastic bottles (1.5L)	Weight (kg)
PET	0.008	1	1	1	0.008	2	750	375	11.25	
Filling LDPE X HDPE	0.05	0.9	0.9	0.81	0.0405	253.125			2.3540625	
Wood pieces	0.05	0.95	0.05	0.0475	0.002375	4			5.7	
Total	0.108	2.85	1.95	1.8575	0.050875	259.13	750	375	19.3	

ONE BACHA (50 PANELS)	50	Thickness (m)	Length (m)	Width (m)	Area (m2)	Volume(m3)	Count	Small Plastic bottles (0.5L)	Large Plastic bottles (1.5L)	Weight (kg)
Total	5.4	142.5	97.5	92.875	2.54375	12956.3	37500	18750	965.20	

Kaura District	
Amount of people	50,000
People per household	5
Amount of houses	10000
Plastic bottles	4
Bags/ groceries	5
Frequency	3
PET incoming/ week	12
Plastic bag incoming/week	15
PET incoming/ week/ neighbourhood	120000
Plastic bag incoming/week/ neighbourhood	150,000
Number of bachas per week	3.2
Number of bachas per year	166.4

