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Thesis

Design Strategies for Informal Settlements towards Climate Change Adaptation in Eswatini

by

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Declaration

I declare that this dissertation is my own work and has not been previously submitted by me for a degree in this or any other institution. Where reference is made to works of others, citation is made in text and in the reference section. I declare that the applicable research ethics approval has been obtained (Appendix E) for the research described in this work and that I have observed the ethical standards required in terms of the University of Pretoria's Code of Ethics for Researchers for Responsible Research.

Musawenkosi Ndlangamandla
Date: 31 August 2023

Abstract

Climate change holds potentially serious consequences for low-cost residential neighbourhoods. This implies a need to determine how these areas can be managed so that they have capacity to cope with and adjust to climate change. The purpose of this study was to identify design strategies for informal settlements to adapt to the effects of climate change and continue to function and provide appropriate services to its residents. Resilience Thinking Theory was used as a lens for understanding and dealing with change caused by the impacts of climate change. The study, which followed a mixed method research methodology, consisted of interviews, an observation study, precedent study, and focus groups. Interviews informed the extent of the problem and served to identify the climate change effects to which informal settlements in Eswatini should adapt. Observation studies determined the adaptive capacity of a selected informal settlement, Msunduza, Mbabane, to identify areas that require enhancement to increase their adaptive capacity to the effects of climate change. Precedent studies provided possible solutions implemented in other countries from which lessons can be taken. Finally, focal groups were used to evaluate the design strategies that were proposed in the study by synthesising all findings from the research methods. Empirical findings indicated that climate change has an impact on the environment, infrastructure and buildings. The results further revealed that informal settlements have a low adaptive capacity to climate change. However, there are traces of good resilience of water management systems to flooding in some parts of the selected informal settlement. The precedent study indicated how green technologies have been used to contribute to the resilience of different projects in similar climatic and socio-economic contexts. Focus group discussions identified design strategies for buildings, infrastructure, and resources suitable for the context of Eswatini. The research output was a design toolkit that could serve as a guide to developers of new affordable residential neighbourhoods, formal upgrading of informal settlements, and to residents retrofitting their self-help houses. The toolkit offered in this study is believed to contribute to the development of affordable settlements that will adapt to the impacts of climate change. The study further contributes a framework that can be used or further developed to assess the adaptive capacity of informal settlements to the impacts of climate change.

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List of Abbreviations and Acronyms

CCA	Climate Change Adaptation
COP	Conference of Parties
CityRAP	City Resilience Action Profiling Tool
CRED	Centre for Research on the Epidemiology of Disasters
CRI	City Resilience Index
CRPT	City Resilience Profiling Tool
DHS	Department of Human Settlements (South Africa)
DiMSUR	Disaster Risk Management Sustainable and Urban Resilience
EEA	Eswatini Environmental Authority
ENHB	Eswatini National Housing Board
EWSC	Eswatini Water Service Corporation
GHG	Greenhouse gases
INDC	Intended Nationally Determined Contributions
IPCC	Intergovernmental Panel on Climate Change
MHUD	Ministry of Housing and Urban Development
NCCP	National Climate Change Policy
MTEA	Ministry of Tourism and Environmental Affairs
NCCSC	National Climate Change Steering Committee
NDMA	National Disaster Management Agency
NHP	National Housing Policy
SACU	Southern African Customs Union
SDGs	Sustainable Development Goals
SES	Social ecological system
SNL	Swazi Nation Land
TDL	Title Deed Land
UDP	Urban Development Project
UN	United Nations
UNDESA	United Nations Department of Economic and Social Affairs
UNDRR	United Nations for Disaster Risk Reduction
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change

PART I: CONTEXT OF THE STUDY

Chapter 1: Introduction and Background

1.1. Introduction

The current (2021) global urban population is estimated at 4.4 billion people, that is 56% of the world's population (UN, 2022). A majority of this population lives in less developed urban areas where the rate of urban population and urban growth is the highest. It is predicted that the population in these areas, mostly located in Asia and Africa, will reach and exceed 2 billion people by 2050, leading to a high demand for housing, basic services, and resilience to climate change impacts (UN, 2018; UN, 2022).

The rapid urbanisation and expansion of urban cities escalates the growth of vulnerable communities living in informal settlements, often located on land that is at high risk from extreme weather (Revi et al., 2014). This rapidly increasing informal settlement population, currently estimated at 1 billion (UN, 2022), is acutely affected by climate change (Roy et al., 2018). The Intergovernmental Panel on Climate Change (IPCC) blames this on the lack of “risk-reducing infrastructure” (paved roads, storm and surface drainage, piped water, etc.) and services relevant to resilience, which expose these settlements to high risks of floods, storms and heatwaves (Revi et al., 2014).

This study aims to provide a toolkit that will guide practitioners responsible for upgrading informal settlements and informal settlement residents to improve the adaptive capacity of these settlements to the impacts of climate change to keep them functional. The study is framed within the discourse of urban spatial resilience believed to hold a solution to address neighbourhood resilience to the effects of climate change. Several authors (Alexander, 2013; Dhar & Khirfan, 2017; Du Plessis, 2012a; Nel, Du Plessis & Landman, 2018; Peres, Du Plessis & Landman, 2017; Tong, 2021; Wilkinson, 2012; Walter & Salt, 2006) established a basis for this study as they hold the view that ecological resilience theory can be translated in urban systems to induce their adaptability to disturbances, including disturbances from climate change.

The objective of the study is to identify design strategies which will develop the capacity of informal settlements to adapt to the impacts of climate change. To achieve the objective of the study, the main research objective relies on four sub-objectives to interrogate the climate change impacts which the informal settlements should adapt to, evaluate the adaptive capacity of a selected informal settlement in Eswatini, learn from relevant solutions to similar challenges globally, and finally propose relevant solutions to the problem of the study.

This chapter introduces the research by presenting the background of the global climate change problem and its manifestation in the context of Eswatini which is the study area, with the purpose of framing the research question which is the departure point of the study. The main research approach, limitations and assumptions of the study, and the motivation of the study are presented. An overview of the structure and contents of the document is provided at the end of this chapter.

1.2. General Background to the Study

The study arises from the rapid global changes resulting from urbanisation and climate change which seem to have enormous effects on cities and neighbourhoods. Global urbanisation is believed to be the major driver of climate and environmental change (Seto, Güneralp & Hutyra, 2012). Expanding on this claim, the authors state that global urban land cover might triple between 2000 and 2030, which will exert pressure on ecosystems which offer ecosystem services such as air purification, water provision, climate regulation and food production in cities (Seto et al., 2012). Expansion of urban areas is expected to be more rapid in cities of the global south countries (UN, 2018) which are mostly found in highly biodiversity rich areas. These areas lack planning and infrastructure to manage rapid urbanisation, therefore leading to degradation of ecosystem services (Nagendra, et al., 2018). The impact of these challenges varies across different parts of the world (Clegg & Sandeman, 2019) demanding resilient responses that will manage the urban systems and maintain the provision of ecosystem services.

Climate change is considered as one of the main and urgent problems faced by humanity in the 21st century (IPCC, 2021). The Fifth Assessment Report (AR5) of the IPCC highlights climate change as the most severe and challenging social, economic and environmental problem the world is facing today (IPCC, 2014). The frequency and severity of disasters caused by climate change is claimed to be causing economic damage and loss of life, among other effects (Tong, 2021). In 2019, the Centre for Research on the Epidemiology of Disasters (CRED) recorded 396 climate change related disasters with “11,755 deaths, 95 million people affected and 103 billion US$ in economic losses across the world” (CRED, 2020). Floods are claimed to have been the deadliest in 2019, followed by extreme temperatures and storms (CRED, 2020). Human and natural systems have and are still being altered by the rise in temperature, causing an increase in drought events, floods, and some other types of extreme weather, sea level rise and biodiversity loss (IPCC, 2014).

These rapidly increasing changes resulting from climate change amongst other drivers, seem to affect cities the most, and they will be unmatched in scope and speed (Nel et al., 2018). Rędzińska and Piotrkowska (2020) state that cities with their inhabitants are vulnerable to the effects of climate change which negatively affects human health, quality of life and urban infrastructure. Several authors (Broto, 2015; Childers et al., 2015; Muchandenyika, 2015; Ndebele-Murisa et al., 2020) claim that Southern African cities are more vulnerable to climate variability and its associated effects, and these are likely to increase in future. On the other hand, the rapid increase of population in cities, which the UN (2012:3) expects to rise from "2.7 billion in 2011 to 5.1 billion by 2050" in developing countries alone, puts pressure on housing and service provision to residents (Ooi & Phua, 2007:30). Roberts (2008:4552) also discusses the possible effects of climate change on the built environment, stating that climate change presents challenges for buildings such as "winter storm damage, an increase in the risk of flooding, increased demand for summer cooling, increasing thermal discomfort in buildings, increased subsidence risk in subsidence prone areas, water shortages and prolonged drought".

According to Roy et al (2018), climate change impacts are more severe for informal settlement dwellers due to their ill-preparedness for climate change. Their vulnerability comes mainly as a result of their formation outside the formal laws and regulations on land ownership, land use and buildings, according to Satterthwaite et al. (2020). This implies that as they are illegally formed, these areas are not guided in development, leaving them vulnerable to climate change impacts from flooding, heavy storms and heat waves.

This changing climate seems to present design challenges to planners and designers in the built environment, as a minimum rise in temperature can increase the frequency and intensity of hazards causing infrastructure and building damage (Basyouni, 2017). There is a concern about the resilience of cities, more especially in vulnerable and underdeveloped regions in Southern Africa. This results from the poor connectivity and fragility of the urban ecosystems (Ndebele-Murisa et al., 2020). Practitioners should therefore develop strategies that will improve the resilience of vulnerable areas and prevent them from collapsing.

Resilience Theory is reviewed in this study to investigate how it can provide a solution to areas vulnerable to the impacts of climate change. Resilience Theory provides a framework for dealing with change. The general purpose of resilience has been described as understanding and addressing change in a dynamic system and the behaviour of a living system through adaptation and transformation, among other strategies, and is believed to offer a solution to the survival of urban systems by several advocates of this paradigm (Dhar & Khirfan, 2017; Li et al., 2014; Peres et al., 2017; Ribeiro & Gonçalves, 2019).

Resilience Theory offers several strategies for understanding and managing change in complex systems. Walker and Salt (2006) reviewed five case studies to investigate the application of resilience thinking in addressing the problems in the real world. Some studies have unpacked the idea of spatial resilience discussing ways in which variations in spatial configurations affect the resilience of urban systems across multiple spatial and temporal scales (Cumming, 2011; Salat, Labbé, & Nowacki, 2011). Most of the resilience literature discusses general urban resilience with limited focus on buildings and informal settlements, which are more vulnerable to change and disruption. This can be blamed on the scarcity of informal settlement data due to the difficulty in collecting data in these areas (Satterthwaite et al., 2018). Poulsen, Lauring, and Brunsgaard (2020) confirm that there is very little focus on research on adaptation of buildings to the unavoidable changes in climate. With occupants spending about 90% of their time indoors, climate change issues must be addressed not only at neighbourhood level and in the exterior of the buildings but also in the interior (Poulsen et al., 2020). This study aims to contribute to the understanding of the spatial and physical resilience of informal settlements by asking the following question: how can informal settlements (buildings and infrastructure components) be prepared (designed or retrofitted) for perturbations caused by climate change so as to maintain their identity and functionality, prevent disturbances from affecting the city, and ensure recovery from climate impacts such as natural disasters? The study uses resilience thinking to frame and address this question.

A relevant study area, Msunduza informal settlement, Eswatini, already affected by the impacts of climate change, has been purposely selected to explore how Resilience Theory can contribute to the identification of suitable design and planning interventions to address climate change disturbances in vulnerable areas such as informal settlements. The following section outlines the problem statement of this study which guides the rest of the research.

1.3. Problem Statement

The World Bank predicts that by 2030 climate change threatens to push millions of Africans into poverty and unravel hard-won development gains (Hallegatte, 2016). The UN International Organization for Migration further suggests that millions to a billion people will be climate refugees requiring accommodation by 2050 and beyond (UN Migration, 2022). At the same time urbanisation rates in Sub-Saharan countries are spiralling (Ndebele-Murisa et al., 2020) and the continent faces a significant housing crisis. Eswatini, also facing similar challenges with other Southern African countries, is implementing measures to provide affordable housing through upgrading of vulnerable residential neighbourhoods in rapidly growing urban areas. However, the current solutions rarely, if ever, consider the current and future impact of climate change on the well-being of residents and their neighbourhood communities.

Informal settlements, without the capacity to adapt to the unavoidable disturbances caused by climate change, are under threat from malfunction from climate change effects which will further exacerbate the housing crisis, poverty, and general well-being of residents. The vulnerability of these settlements results from poor planning, among other reasons, which does not consider building climate change resilience into the components that make up the settlements.

To address this problem, the following section presents the main research question and sub sections which the study addressed.

1.4. Main research question

The main research question guiding the study is:
What design strategies can be employed to improve the capacity of informal settlements in Eswatini to adapt to the impacts of climate change?

1.4.1. Sub-question 1

Which predicted climate change effects require an adaptive response from informal settlements in the context of Eswatini?

1.4.2 Sub-question 2

What is the current adaptive capacity of informal settlements in the context of Eswatini?

1.4.3. Sub-question 3

How have other projects addressed the adaptation of residential settlements to climate change impacts?

1.4.4. Sub-question 4

Which design strategies could be suitable for informal settlements in Eswatini to increase their capacity to adapt to the impacts of climate change?

1.5. Research Objective

The objective of this study is to develop design strategies which will increase the capacity of informal settlements to adapt to climate change.

1.5.1. Sub-objective one

To identify climate change effects to which informal settlements in Eswatini should adapt.

1.5.2. Sub-objective two

To assess the adaptive capacity of informal settlements in Eswatini to climate change.

1.5.3. Sub-objective three

To investigate approaches to climate change impacts adaptation of residential settlements.

1.5.4. Sub-objective four

To evaluate design strategies that could be suitable for informal settlements in Eswatini to increase their adaptive capacity to the impacts of climate change.

1.6. Limitations, delimitations and assumptions of the study

1.6.1. Limitations

a. Climate data which was accessible spanned from 1981 up to the year 2020.
b. Observation studies were conducted in only one selected informal settlement, Msunduza, due to time constraints.
c. Statistical findings from the observation study are only applicable to the neighbourhood that was documented. Generalising these findings to other neighbourhoods will require further mapping to be undertaken.
d. Local (Africa) precedents reviewed in the study were taken from a book titled: ‘A Manifesto for Climate Responsive Design’ by Clegg and Sandeman (2019).
e. The selected local precedents mainly addressed extreme heat effects due to their location in East Africa, while international (other regions) precedents addressed flooding, storms and drought effects.
f. The study reviewed twenty precedent studies due to time constraints.
g. Information about informal settlement upgrading and conditions of informal settlements in Eswatini was only accessed from MHUD (2007).

1.6.2. Delimitations

a. The study only focused on informal settlements in the context of Eswatini.
b. Resilience is considered in different dimensions of the city, however the study only focused on the physical dimension, which is spatial resilience.

1.6.3. Assumptions of the study

a. The study is framed within the resilience thinking theory believed to provide a framework to maintain the function and identity of informal settlements and further regenerate in the midst of or after perturbations caused by climate change.
b. The study used Msunduza Informal Settlement as a case study purposely selected with the assumption that results will be the same for similar cases in the same context, achieving literal replication.

1.7. Definitions and terms

- **Informal settlement** - "generally refers to urban settlements that develop outside the legal systems intended to record land ownership and tenure and enforce compliance with regulations relating to planning and land use, built structures, and public health and safety" (Satterthwaite et al., 2020:143). The study uses the definition by Ploeger and Groetelaers (2006:1) which defines informal settlements as "dense spreading of shelter units constructed of diverse materials and built on privately or government owned property without a title deed by the occupants". The term is also applied to such settlements which are already undergoing formalisation where some of the buildings can be considered formal, where the owner has a title deed and construction documentation of the building is regulated by the local authority.

- **Climate change adaptation** - The IPCC defines climate change adaptation as "adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (Pachauri & Reisinger, 2008:869). "Adaptation is conceived of as a dynamic phenomenon – as a process rather than a status… the dynamism of climate change requires an adaptation that can coevolve with it" (Pelling, 2011:7).

- **Transformation -** "Transformation denotes the move from one level of development to another and is distinct from "translation" which is the broadening and strengthening of capacities at a particular stage of development" (Ziervogel, Cowen & Ziniades, 2016:3).

- **Resilience** - "The capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" (Walker, Holling, Carpenter and Kinzig, 2004:4).

- **Regenerative development -** "An approach that is about enhancing the quality of living beings to co-evolve so that our planet continues to express its potential for diversity, complexity and creativity" (Mang & Haggard, 2016).

1.8. Motivation for the study

Climate change has escalated the frequency and severity of climate-related disasters to such an extent that the study of urban resilience has been considered an important area of research (Tong, 2021). Such changes are predicted to be unprecedented in the near future in both scope and speed (IPCC, 2021). Climate related disasters have been linked to economic damage, loss of life, and negative effects on human and natural systems (CRED, 2020; IPCC, 2014; Tong, 2021), which provides a sense of urgency in addressing the impacts of climate change. Managing such changes in cities (complex adaptive systems) has become more important than ever, yet practitioners such as planners seem to lack the skills on how to plan and design for change (Nel, Du Plessis & Landman, 2018).

Addressing the unavoidable and uncertain climatic changes in cities requires not only mitigation strategies, but also strategies aiming for adaptation and transformation of neighbourhoods to maintain their function and further become better cities. This study argues that such a solution can be found in the exploration of Resilience Theory which provides a framework for dealing with system perturbations such as those caused by climate change. Informal settlements which are more vulnerable to climate change impacts in comparison with the more formal parts of the city, are believed to be a necessary starting point to improve the city's adaptive capacity in an attempt to minimise the intense effects of climate change and support the settlements to flourish.

The study therefore contributes to the urban resilience and climate change adaptation discourse, and specifically urban spatial resilience, by proposing design strategies for informal settlements to adapt to the impacts of climate change and ensure survival of informal settlements experiencing perturbations caused by climate change. The proposed solutions bridge the gap between theory and practice. The findings of the study will contribute to the advancement of the Urban Resilience Theory, and enable practitioners, such as urban planners, architects, engineers and environmentalists, to contribute to policy making as well as the physical development of the city, to improve its resilience to climate change.

The context of the study is in Eswatini, which is already affected by the impacts of climate change, especially on the country's key economic sectors. Such impacts come from the observed changing precipitation patterns, increases in average temperatures, and high storm intensities (MTEA, 2011). The Ministry of Tourism and Environmental Affairs has responded through a vast number of policies and institutional structures related to aspects of climate change, but they do not seem to be climate change specific. The built environment sector has further not been well addressed as the focus is on the agriculture sector. With the climate change unit at the MTEA also aiming to address climate impacts in the built environment, the study will contribute to devising strategies to address such in urban areas.

1.9. Overview and structure of the dissertation

The dissertation is sectioned into three parts. Part 1 presents the introduction, background and context of the study. Part 2 presents the actual research undertaken to consider the four research objectives. Lastly, part 3 presents the outcome of the dissertation, which is a synthesis of the work undertaken in the research, and addresses the overall research question of the study. The following describes the contents of each chapter.

Part I: Context of the study

Chapter 1

The introductory chapter of this research presents the background on the global climate change discourse, highlighting the general impacts of changes in climate globally and narrows to the effects on cities and informal settlements. The main problem of the study is presented, namely that informal settlements are under threat of malfunctioning from the impacts of climate change that will further exacerbate the housing crisis and poverty in these areas in Eswatini. Four research sub-objectives are provided. The first sub-objective seeks to identify the specific climate change impacts to which informal settlements in Eswatini should adapt. The second sub-objective seeks to determine the adaptive capacity of informal settlements using the study area, Msunduza in Mbabane, Eswatini. The third sub-objective sought to identify existing and proposed solutions globally to similar challenges. And the last sub-objective sought to identify suitable design strategies for Eswatini that can act as a guide towards building informal settlements that are resilient to the identified climate change impacts. This chapter is concluded by giving a motivation of the study.

Chapter 2

This chapter mainly reviews existing literature with the aim to understand the global as well as local climate change problem, the urgency to address the problem, and the theoretical framework of resilience thinking as a guiding mechanism. This review is focused on literature which pertains to climate change, the nature of and vulnerability of informal settlements, resilience thinking, and current resilience assessment frameworks.

The chapter starts by defining and discussing the background of global climate change and its effects. Further, global responses to climate change are reviewed. The study narrows down to review literature about climate change effects on the built environment, and eventually informal settlements. A potential link between climate change and informal settlements is investigated. The study explored approaches in resilience thinking, and this theory is reviewed to frame the study. Spatial resilience and its attributes are explored to create a framework for reviewing a selected informal settlement in later chapters. Further, resilience assessment methods are reviewed to inform the observation schedule.

Chapter 3

Chapter three outlines the research methodology used in this study. The study used Msunduza Informal Settlement as a case study purposely selected with the assumption that results will be the same for similar cases in the same context, achieving literal replication. To fully understand climate change effects, vulnerability of informal settlements, and possible design solutions in informal settlements; a mixed research method was employed. The study followed a pragmatic approach, with all research sub questions using different research methods that best addressed that particular sub question. The setting of the study, research design, population and sample strategy to respond to each sub research question are discussed in detail in this chapter.

Chapter 4

This chapter presents a description of the context within which the study was undertaken. The chapter discusses the location, general economic, geographical and climatic context of Eswatini. Finally, Msunduza in its current condition is discussed. This chapter is not exhaustive in any way, but rather sets out to give a short description of the larger context within which the study was undertaken.

Part II: Research

Chapter 5

This chapter responds to the first sub-objective, which sought to identify climate change impacts to which informal settlements in Eswatini should adapt in order to thrive. Interviews with experts from different professions affected by climate change responded to this sub objective and the results were discussed in detail in this chapter. A conclusion is made about the climate change impacts to which informal settlements should adapt, and this data feeds into the next sub-research questions.

Chapter 6

This chapter responds to the second sub-objective, which seeks to determine the adaptive capacity of informal settlements in the context of Eswatini. Data collected through a semi-structured physical observation was analysed to determine the adaptive capacity of the selected informal settlement. Areas with good adaptive capacity and those that require enhancement were identified. Tables, diagrams and maps were used to present data. Challenges encountered when collecting data, failure, and success are discussed in this chapter.

Chapter 7

This chapter presents findings to address sub- question three: “How have other projects addressed the adaptation of residential settlements to climate change impacts?” Purposely selected international climate change responsive designs, drawing largely on the work of Clegg and Sandeman (2019), and suggestions of local experts were reviewed, synthesised and presented in this chapter. The aim was to learn from other precedents which have addressed similar climate change challenges. This chapter is concluded by providing a list of strategies that can be used to increase the adaptive capacity of residential neighbourhoods to the impacts of climate change.

Part III: Outcome

Chapter 8

This chapter responds to the fourth sub- question: “Which design strategies can be suitable for informal settlements in Eswatini to increase their capacity to adapt to the impacts of climate change?” Findings from the first sub- questions were synthesised to propose design strategies which can increase the adaptive capacity of informal settlements. These design strategies were reviewed through focus groups, and the results are presented as a collection of suitable design strategies for informal settlements in Eswatini. Following the review of the strategies by experts, a final set of the design strategies are presented in this chapter in a form of a design toolkit to respond to the main research question of the study: “What design measures can be taken to improve the capacity of informal settlements in Eswatini to adapt to the impacts of climate change?”. A framework aimed at developing design strategies of informal settlements also comes as an output of this study which is presented in this chapter.

Chapter 9

Conclusions are made about the objectives and findings are summarised and made understandable to the reader. The contributions of the study are stated, and suggestions for further research are presented in this chapter. Finally, recommendations following the research are proposed to conclude the study.

Chapter 2: Literature Review

2.1. Introduction

This chapter reviews existing literature which is related to the study topic, with the aim of exploring the general global and local context of the study. This review is focused on literature pertaining to the global problem of climate change; vulnerability of informal settlements to climate change; resilience thinking as a theoretical lens framing the study; urban resilience; and a review of climate change resilience assessment frameworks. The structure of the literature review is presented in Table 2.1.

Table 2.1. Structure of the literature review chapter

2.1. Introduction	**2.2. Climate change**	**2.3. Informal settlements**	**2.4. Resilience thinking**	**2.5 Urban Resilience**	**2.6. Urban Resilience Assessment Frameworks**
	2.2.1. Impacts of climate change 2.2.2. International response to climate change 2.2.3. Climate change adaptation	2.3.1. Formation of informal settlements 2.3.2. Causes of development of informal settlements 2.3.3. General location of informal settlements 2.3.4. Vulnerability of informal settlements 2.3.5. Current intervention approaches	2.4.1. Types and Perspectives of resilience 2.4.2. Resilience of Social-ecological systems 2.4.4 Resilience thinking concepts	2.5.1. Urban Resilience and Sustainability 2.5.2. Urban Resilience and Regenerative Development 2.5.3. Characteristics of Urban Resilience 2.5.4. Determining the resilience of a system 2.3.5. Urban Climate Change Resilience	2.6.1. City Resilience Index 2.6.2. City Resilience Profiling Tool 2.6.3. Disaster Resilience Scorecard for Cities 2.6.4. City Resilience Action Planning Tool 2.6.5. Resilience Alliance Assessment Framework

The chapter discusses the global climate change discourse reviewing the impacts of climate change in cities globally, in southern Africa, and climate impacts at building level. The discussion further shifts to review international responses to climate change in the built environment. Eventually the problem of climate change is discussed in the context of informal settlements. The nature of informal settlements is discussed to understand their formation, vulnerability and current global responses.

Current approaches and theories on addressing change in general are discussed, with a focus on Resilience Theory which the study is rooted in. Resilience thinking and urban resilience literature is explored for how it can provide understanding of change in urban systems including informal settlements, and further provide solutions to the problem. Existing literature on resilience thinking and urban resilience is reviewed to determine how a resilient neighbourhood with capabilities of recovering from previous impacts should be structured.

The chapter is concluded with a review of different international frameworks to learn how they are structured and implemented to assess and improve the resilience of cities to disasters. The most relevant resilience assessment framework which can be used to assess the resilience of informal settlements is identified.

2.2. Climate Change Background

Climate change is considered as one of the most urgent challenges faced by humanity in the 21st century (IPCC, 2021). This century has been characterised by alterations in climate and demographics. This condition of climate change is attributed to the increase of GHG in the atmosphere as a result of anthropogenic activities (IPCC, 2014; Stagrum, Andenaes, Kvande & Lohne, 2020). These GHGs capture more thermal energy, which causes the global average temperatures to increase (Stagrum et al., 2020). The increased warming of the earth's surface is termed as 'global warming'. The earth's surface temperature has an impact on the atmospheric climate (Pachauri et al., 2014). A slight increase in average temperature changes weather patterns. Therefore, the two terms 'climate change' and 'global warming' cannot be dissociated. Global warming is depicted by average temperatures which were measured since 1880 and climate change measures changes in weather patterns over a long period of time, which could go as far as decades or centuries.

The built environment is claimed to be responsible for a third of GHG emissions as a result of construction of buildings, consumption of resources, creation of waste and emission of pollution during the life cycle of the buildings (Zari, 2008). Huovila et al. (2009) state that a high amount of greenhouse gas emissions come from construction materials. Such materials include insulation materials, and refrigeration and cooling systems. The use of energy in the built environment increases the demand of burning fossil fuels for energy to be used for heating, electricity, transport, and industry, among other needs. The use of energy in the built environment therefore adds to the increase in emissions of GHG into the atmosphere. Huovilla et al. (2009) clarify that energy in the built environment is mainly consumed during the following activities: "manufacturing of building materials ('embedded' or 'embodied' energy); transport of these materials from production plants to building sites ('grey' energy); construction of the building ('induced' energy); operation of the building ('operational' energy); and demolition of the building (and recycling of their parts, where this occurs)" (Huovila et al., 2009:10). The highest amount of energy is however used during the operational phase of a building (Huovila et al., 2009). The author further claims that the residential sector contributes a greater portion of energy consumption in most countries.

According to IPCC (2014), urban areas consume about 70% of the world's energy. This percentage continues to increase as the urbanisation rate increases and with it, an increased demand of energy from the building sector [UN, 2018]. Cities are claimed to contribute the most to climate change due to high GHG emissions. They are the most affected by climate change effects, and at the same time have the greatest potential to adapt to climate change through solutions which build resilience (Ndebele-Murisa et al., 2020).

Rędzińska and Piotrkowska (2020) state that cities with their inhabitants are vulnerable to the impacts of climate change, which has a negative impact on the wellbeing of humans and urban infrastructure. The following section expands the discussion about the effects of climate change.

2.2.1. Impacts of Climate Change

Human and natural systems have and are being altered by the rise in temperature, causing "increases in droughts, floods, and some other types of extreme weather; sea level rise; and biodiversity loss" (IPCC, 2014). Volcanic activities, hurricanes, heightened storm intensity, and frequent heat waves, are other observed weather-related events resulting from climate change, which alter human and natural systems (IPCC, 2021). Figure 2.1 presents the number of weather-related events in Africa between 1980 and 2021, which clearly seem to be generally intensifying. The diagram presents a gradual increase in frequency of all the presented natural disasters from 1980 to 2021. The diagram further shows that most natural disasters result from flooding events. There was, however, a drop in the number of flooding events between 2010 up to 2018 which is a period that experienced extreme drought.

Climate change and the resulting natural disasters affect millions of people globally by damaging crops, reducing access to water, and eroding coastlines, among other impacts (World Bank, 2016). These changes are causing risks mostly to the vulnerable living in low- and middle-income countries, with some linked to decline in food security, migration, and poverty (IPCC, 2014). Some of the effects are observed in the physical structure of a city.

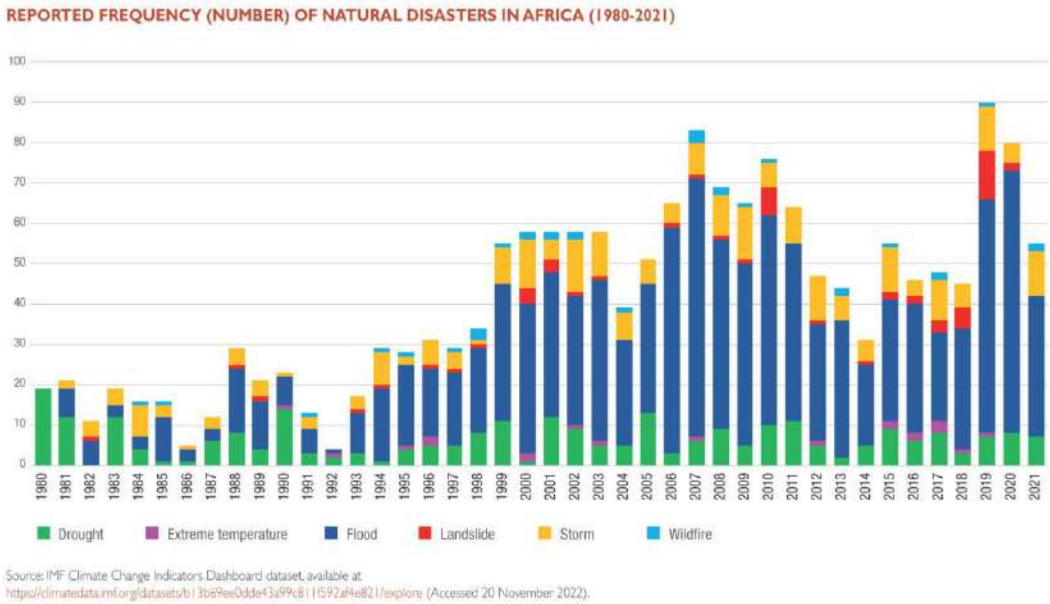


Figure 2.1. Frequency of natural disasters in Africa in the period of 1980 - 2021 (IMF, 2021)

Roberts (2008:4552) suggests that climate change presents challenges for buildings such as “winter storm damage, an increase in the risk of flooding, increased demand for summer cooling, increasing thermal discomfort in buildings, increased subsidence risk in subsidence prone areas, water shortages, and prolonged drought”. Buchin et al. (2016) also raise the point that buildings are likely to contribute the most to urban heat island effects and GHG emissions because of an increased demand for cooling and also the use of electric cooling systems, if they are not designed to adapt to climate change. This will negatively affect the health of the residents if the rising cooling demands are not met (Buchin et al. 2016). Stagrum et al. (2020) confirm that climate change is expected to have severe effects (Table 2.2) for a built environment which was designed under assumptions of steady conditions. Effects of climate change on buildings have further been listed by Basyouni (2017) as presented in Table 2.2.

Literature in general predicts that climate change effects which settlements should adapt to can be classified as: overheating effects, flooding effects, storm effects, and effects caused by fire (Table 2.2) (Basyouni, 2017; Buchin et al., 2016; Roberts, 2008; Stagrum et al., 2020). Stagrum (2020) argues that climate change effects are different for different regions, stating that in hot climates the major effect for the built environment is overheating and drought. In cold climates along coastal areas increased average temperatures and precipitation are expected.

Table 2.2. Impacts of climate change on buildings

Climate change	Building impacts
Rising temperature	Building envelope impacts; impact on thermal performance
Intense rainfall	High runoff intensity; effects on structural integrity; drainage effects
Intense cyclones	Effects on building materials, claddings and fasteners
Flooding	Sea level rise; damage of building contents; undermining of foundations
Fire events	Fire damage; smoke and water damage
Hailstorms	Damage on roofs, gutters and windows; moisture penetration
Increased humidity	Mould; condensation; reduced thermal performance of buildings
Decrease in humidity	Increased risk of fire

Several authors (Broto, 2015; Childers et al., 2015; Muchandenyika, 2015; Ndebele-Murisa et al., 2020) claim that Southern African cities are more vulnerable to climate variability and its associated effects, and these are likely to increase in future. There is a concern about the adaptive capacity of these cities, more especially in vulnerable and underdeveloped regions in Southern Africa considering the poor connectivity and fragility of the urban ecosystems (Ndebele-Murisa et al., 2020).

This changing climate seems to present design challenges to planners and designers in the built environment, as just small increases in temperature, for instance, can dramatically increase hazards causing building damage (Basyouni 2017). However, even with all the scientific agreement on climate change, buildings and cities are still designed/planned, built and operated inefficiently and unsustainably. Hausladen, Liedl and de Saldanha (2012) mention that architects will in future have to design structures with guidance of detailed climatic analysis. Buildings and cities should, therefore, be designed, planned and developed to meet current and future environmental and societal pressures (Basyouni 2017; Kinnane, Grey & Dyer, 2016). According to Huovila et al. (2009), the built environment (especially in cities) has the highest potential to reduce energy consumption at the lowest cost. There is an urgent need to respond to climate change in cities; and the response should be swift, flexible, and created to develop systemic, sustainable and resilient solutions.

There are international responses to climate change that have taken strides towards addressing the global challenges of climate change as discussed in the following section.

2.2.2. International response to Climate Change

Following the discovery of the correlation between global average temperature increases and global carbon dioxide emissions, there were several global responses proposed over the years aimed at addressing the global climate change problem. These include a number of crucial meetings which include the Club of Rome meetings, held in 1970, where the climate change challenge was first discussed. Another action was the establishment of the Intergovernmental Panel on Climate Change in 1988, then in 1992 during the Earth Summit, which was held in Rio de Janeiro, the United Nations Framework Convention on Climate Change (UNFCCC) was established (Roaf et al., 2009). A Conference of Parties (COP) was also initiated in 1995, with the first one (COP1) being held in Berlin in the same year. These conferences have been held annually since 1995 to take important collective decisions and make agreements about climate change (Roaf et al., 2009). There are two important global treaties that have emerged out of these meetings and other global platforms: the Kyoto Protocol and the Paris Agreement.

- **Kyoto Protocol**

The Kyoto Protocol is considered the first agreement established during the third COP conference in Kyoto, Japan in 1997, with the aim of lowering global carbon emissions to 5% beneath the 1990's level by 2012 (UN, 2008). Following delays in endorsement by several countries, this treaty came into effect in 2005 when it was ratified by 192 nations. The Kyoto Protocol's first commitment period came to an end in 2012, but a second commitment period was agreed to, which came to an end in 2020. This treaty focused on reducing emissions of the top six impacting GHG types (UN, 2008). The strategies and responsibilities agreed upon was to reduce GHG emissions by improving technology efficiencies, encouraging GHG sinks, altering subsidies and adjusting economies to encourage GHG reduction, and encouraging cooperation in order to ease knowledge and technology sharing (UN, 2008).

This treaty had specific targets set for each country depending on their GHG emissions, and allowed carbon trading, which potentially made it more meaningful when compared to the Paris Agreement (Satgar, 2018), however it is considered to have had limited successes (Roaf et al., 2009). One of the shortfalls is seen as the focus on lowering carbon emissions and disregarding the significance of Climate Change Adaptation (CCA) (Satgar, 2018).

- **The Paris Agreement**

The Paris Agreement is referred to as a legal framework aimed at promoting and facilitating economies to become carbon neutral (UN, 2015). It was adopted in December 2015 at the UN Climate Change Conference (COP21) in Paris, France. Countries have a choice to report and devise strategies aimed at mitigating climate change (Climate Focus, 2015), and a total of 196 countries have signed this agreement.

The Paris Agreement has a focus on GHG mitigation by encouraging voluntary participation of countries to report about their GHG emissions. This agreement also acknowledges the importance of devising climate change adaptation strategies, especially within vulnerable communities (UN, 2015). This agreement further encourages the use of a Nationally Determined Contributions (NDC) mechanism where countries determine their own GHG emission mitigation goals to undertake their mitigation measures (Climate Focus, 2015). The NDC is compiled and shared every five years. In addition, the Paris Agreement calls for a public fund to be established to aid developing countries to develop climate adaptation projects (UN, 2015).

It is noted that while the agreement was signed in 2015, commencement with carbon mitigation measures only occurred in 2020 and the first global stocktake is expected to take place in 2023 (UN, 2015). This on its own does not show the urgency which the climate change situation demands. The voluntary participation may have risks of little commitment from countries in mitigating GHG emissions. Climate change adaptation methods may prove beneficial in this situation to enable countries to adapt to unexpected effects that may arise while countries are slowly rolling out mitigation measures. Climate change effects may not be avoidable, which requires an emphasis on developing the adaptive capacity of countries, especially the most affected developing countries, to be resilient to the impacts of climate change.

2.2.3. Climate change adaptation

Poulsen, Lauring, and Brunsgaard (2020) state that most efforts towards addressing climate change in the building sector were concentrated on mitigation through reducing energy use, but there is barely a focus on adaptation of buildings to the unavoidable changes in climate. Poulsen et al. (2020) further noted that in most design and research projects, the focus has been on the mitigation of flood risks and urban heat island effects, with minimal focus on climate change adaption of buildings.

Zolnikov (2019), suggests a combination of adaptation and mitigation strategies to address climate change effects, proposing that mitigation actions may take a long time to be effective, so while awaiting the results of mitigation, adaptation must occur (Zolnikov, 2019). Pelling (2011) argues that mitigation is a subset of adaptation, with mitigation focusing on addressing causes of climate change by reducing or reversing contributing factors, with examples such as "using clean or renewable energy, eating a plant-based diet, driving an electric car, using energy-efficient lighting, reducing energy consumption, planting trees, policy measures" amongst others (Pelling, 2011:3) which seem to relate to green practices. Adaptation is understood by Pelling (2011) as involving actions aimed at reducing vulnerability to future environmental changes or challenges (Zolnikov, 2019:4).

It is confirmed in literature that new buildings should be designed in such a way that they can cope with climate change (Hausladen, Liedl & Saldanha, 2012; Kinnane et al., 2016; Poulsen et al., 2020; Roberts, 2008). With occupants spending about 90% of their time indoors, climate change issues must be addressed not only in the exterior of the buildings, but also in the interior (Poulsen et al., 2020). The focus should not only be on the buildings but also the inhabitants (Altomonte et al., 2015). These buildings should not only consider past or current climate but the continuous change in climate. It is predicted that newly constructed buildings might face changing climates through their lifetimes. According to Poulsen (2020:114) this will "give rise to issues with regard to energy frame, indoor climate and exposure to extreme events that were not a concern at the time of construction".

The city as a whole should also adapt to climate change impacts to keep functioning. Several responses are required in physical planning of a city such as "hardening up of infrastructure systems, including storm-drainage systems, water supply and treatment plans with protective physical improvements; protection or relocation of solid waste management facilities, energy generation and distribution systems; and consolidation of hydro-geologically fragile areas, and/or ecosystem - and community based adaptation coupled with the transformative adaptation agenda" (Ndebele-Murisa et al., 2020:2). Ndebele-Murisa et al. (2020) further propose that cities engaging in adaptation planning should learn from cities which are successful in adaptation planning. Properly implemented planning of urban areas results in resilient cities and neighbourhoods. Responses should, however, not only focus on urban planning but also consider building design.

The starting point in an attempt to adapt to climate change is logically the most vulnerable communities such as informal settlements. Such settlements carry a quarter of urban population, estimated at 1 billion globally (UN-Habitat, 2018). These settlements are associated with poverty but they are also valued as they are considered a common response to providing housing needs (Hernandez-Garcia, 2013). One out of three people who live in cities sustain themselves in informal settlements (Dovey & King, 2011). These areas, however, have poor adaptive capacity to climate change due to the poor-quality buildings and lack of services that reduce risks (Revi et al., 2014). The following section overviews the nature of informal settlements to give a sense of their vulnerability to climate change.

2.3. Overview of informal settlements

The term ‘informal settlement’ has been given different definitions in literature depending on the context. This makes it critical to define the term in the context of this study. Ploeger and Groeterlaers (2006) define the term according to spatial distribution of units, use of material and legal status. The authors define informal settlements as “spreading of shelter units constructed of diverse materials and built on privately or government owned property without a title deed by the occupants” (Ploeger & Groeterlaers, 2006:1). The UNDESA (2014) also defines ‘informal settlements’ according to legal status, as “areas that do not comply with urban areas’ zone planning schemes, where housing units are constructed on state- or privately-owned land to which the dwellers have no legal claim or permission from the local authorities.” The UN’s definition clarifies that informal settlements are not only associated with the urban poor but belong to all income groups. Some high-cost buildings can also be considered informal if the owners have no title (Potsiou & Loannidis, 2006). The United Nations Economic Commission for Europe (UNECE) characterises informal settlements as, “illegal residential formations lacking basic infrastructure, security of tenure, and adequate housing” (UNECE, 2009:1).

The definitions above agree on the “lack of security of tenure” and “lack of approval of formations from the local authorities.” The definition of the term ‘informal settlements’ is normally compared to the formal part of the city with the belief that they can be formalised in future (Hernandez-Garcia, 2013). Formality refers to the planned, institutional part of the city which is said to be legal (Hernandez-Garcia, 2013). The term ‘legality’ is not clearly defined in literature but the properly planned (formalised) part of the city is considered legal and the informal part is associated with illegality. In general, the term informal settlements is defined according to the physical condition and legal status.

In consideration of the above definitions and the context of this study, the study employs the definition of *informal settlement* which limits these areas to “residential areas with housing constructed on land to which the dwellers have no title but may be in the process of formalisation” (UN, 2001:160). It is important to consider that other informal settlements are under upgrading, however they can only be considered formal settlements upon successful completion of the upgrading process. The focus of this study is on informal settlements considered to be occupied by the urban poor and with poor housing conditions, and may be or may not be under formalisation. Their main characteristics are, "the lack of basic services, living in inadequate structures, overcrowding, unhealthy conditions and poverty" (UNDESA, 2014:2). The following subsections discuss their formations, location, cause of their development, and general climate change effects which need to be addressed. The aim is to determine the vulnerability of informal settlements to climate change and the urgent need to address their adaptive capacity.

2.3.1. Formation of informal settlements

The vulnerability of informal settlements may result from their formation methods which result in certain forms that may have low adaptive capacity levels. Therefore, it is critical to understand the morphology of informal settlements to identify areas of intervention. For instance, formations on flood plains make these settlements vulnerable to flooding. The assumption is that the vulnerability to climate change starts from their formation (construction) stage, through operation, up until demolition stage. The design measures addressing the vulnerability of these settlements should be implemented at their formation unless its already an upgrading mission which should consider retrofitting. There are three primary modes of informal settlements which should be understood (how informal settlements grow) according to Dovey and King (2011):

- Settling – these form on unclaimed land, which was the way cities were formed in the past.
- Inserting – this refers to formations on abandoned land.
- Attaching – this refers to informal settlements which have attached onto structures of the 'legal' city.

Clearly the formation of these forms is not controlled by authorities, but self-made by residents without any guidance, which may be the start of their vulnerability as there are no formal plans to guide developers on building well-functioning, let alone adaptable settlements.

2.3.2. Causes of the development of informal settlements

The formation of the kind of informal settlements with low quality houses and lack of risk reducing infrastructure is blamed on poverty (Bredenoord, 2016; Nassar & Elsayed, 2017). Another cause of the development of these settlements is the lack of formal response to the housing challenge in cities, which forces the urban poor to opt for informal housing (Nassar & Esayed, 2017). A summary of several common factors is highlighted on Table 2.3 below.

Table 2.3. Causes of informal settlement formation

Authors	**Factors**
Bredenoord (2016)	Poverty
Nassar and Elsayed (2017)	Poverty Lack of adequate formal response to housing demand growth
Napier (2004)	Transition from colonialism Poverty Impacts of structural adjustments “Neo-liberal programs on formal welfare for the low-income population”

The common cause of the formation of informal settlements is poverty, however there are other factors discussed by different authors as presented in Table 2.3. Bredenoord (2016) mentions that poverty influences the growth of self-help housing, the type of housing provision system which is mostly incremental and executed in a step-by-step construction process (Wekesa et al., 2011). Literature seems to directly or indirectly agree that self-help housing is often observed in informal settlements (Bredenoord, 2016; Bredenoord, 2017; Devi, Lowry & Weber, 2017; Dovey & King, 2011; Ploeger & Groetelaers, 2006) and should be sustained. Any climate change response should consider addressing self-help housing.

2.3.3. General location of informal settlements

A typology of eight informal settlement (typical conditions rather than building types) is listed by Dovey & King (2011:14) as shown in Table 2.4 below. Waterfronts could be mostly vulnerable to the impacts of flooding as they normally sit on flood prone areas. Escarpments have a risk of being affected by landslides, and sidewalks may not survive heavy storms due to their poor structural integrity. There may be threats to sanitation and safety and they may be more vulnerable to environmental change. The informal settlement types presented in Table 2.4 below demonstrate how informal settlements develop in specific, often vulnerable locations. Some informal settlements may be a hybrid of the types listed, where infrastructure like a railway may be co-located with a waterfront.

Table 2.4. Informal settlement types (Dovey & King, 2011:14)

	Type	**Description**
1	District	Mixed-use districts with retail and industrial functions, which have developed over a long period
2	Waterfronts	Settlements on marginal land between the formal city and the water whether river, canal, lake, or harbour frontage.
3	Escarpments	Settlements are normally on very steep areas which are left undeveloped by the formal city because of their inaccessibility by a car.

	Type	Description
4	Easements	Such areas are located mostly along major urban infrastructure – railways, freeways, power lines, sewer lines
5	Sidewalks	Settlements may follow a public sidewalk and lead to linear housing normally of a single storey and built of cardboards and plastics.
6	Adherences	Informal settlements growing within formal settlements and intrude into public spaces.
7	Backstage	Such informal settlements are invisible, and they develop between buildings of the formal city.
8	Enclosures	These informal settlements are physically located within a certain formal shell within the city which forms the boundaries for the extension of the informal cities. Examples are informal settlements within cemeteries in Indonesia and Egypt.

2.3.4. Vulnerability of informal settlements to climate change

Informal settlements are not well serviced, and they lack risk-reducing infrastructure (paved roads, storm and surface drainage, piped water, etc) and services relevant to resilience (including health care, emergency services and rules of law) (Revi et al., 2014). According to these authors, these settlements are not well prepared for climate change, making them exposed to floods, heavy storms, and heat waves. This is because of poor quality buildings and lack of infrastructure to prevent the effects of climate change (Revi et al., 2014). Considering these conditions, there is an urgent need to build resilience to climate change in these settlements (Satterthwaite et al., 2020), without disrupting their livelihoods and social networks.

There are several informal settlement interventions that have been proposed and implemented to improve living conditions in these areas and some are described below.

2.3.5. Current Intervention Approaches

Governments experiencing the spread of informal settlements in cities have responded through policies, strategies, and programs to address housing demand which results in the development of informal settlements. The preferred way to address housing challenges in informal settlements is believed to be through settlement upgrading (Abbot, 2002; Devi, Lowry & Weber, 2017; Walker, 2016; Wekesa, Steyn & Otieno, 2011). There are several intervention approaches which have been discussed in literature and further implemented with the aim of addressing housing challenges in informal settlements. These interventions, reviewed by several authors (Balbo, 2001; Huchzermeyer, 2011; Wekesa, Steyn & Otieno, 2011) are briefly discussed in Table 2.5 below.

Upgrading informal settlements provides an opportunity to address climate related challenges within informal settlements to keep them functional. At the same time, it is vital for addressing poverty and ensuring access to essential services at low cost and further improving their social status.

Table 2.5. Intervention approaches to housing challenges

Intervention	**Description**
Public housing	This kind of housing, which was common in the 1950s to 1970s, involved relocation of informal settlement residents to state owned housing (Wekesa et al., 2011). These developments had many challenges such as corruption of the contractors, remote areas which led to poor access to job opportunities, and limited living spaces for families (Keivani & Werna, 2001). There is potential for addressing climate change impacts in this housing type where residents are relocated from flood prone areas and poor housing quality to safe locations with housing that has good structural integrity.
Sites and services	Site and service schemes, which were common in the 1970s to 1980s, provided greenfield areas with services and tenure, and the residents were required to self-develop and manage their houses (Balbo, 2001; Keivani & Werna, 2001). The challenge of this intervention was also the access to employment areas, as these areas were normally located in remote and cheap areas away from the city. This approach had a focus on infrastructure, which had a potential of addressing some of the climate change impacts. However, the housing component was left to residents (who had no construction knowledge) to manage.
Informal settlement upgrading	Informal settlement upgrading involved upgrading the brownfields rather than relocating residents to greenfield areas. This method was regarded as the most cost-effective method (Wegelin, 2004). This intervention included installation of basic infrastructure and security of land tenure, with residents focusing on developing self-help housing (Nassar & Elsayed, 2017). This approach was claimed successful (Wekesa et al., 2011). Informal settlement upgrading introduces what IPCC (2014) calls 'risk reducing infrastructure' which has a potential to improve the adaptive capacity of informal settlements. However, it is not clear how the development gains from this intervention are sustained.
Housing production	Self-help housing and social housing are also housing production modes which provide affordable housing to informal settlement dwellers. Self-help

Intervention	Description
	housing is affordable, incremental and self-managed by the residents who also determines the design and quality of the housing (Bredenoord, 2016). Social housing is a housing production where governments engage the private sector to assist in providing affordable housing to the urban poor. This kind of housing is subsidised to reduce rent paid by the residents. Climate adaption is not prioritised. However, since there is proper management of this housing production, this housing typology offers greater potential to adapting to climate change and resisting the impacts of climate change than self-help housing where capacity building would have to be ensured to improve the house designs to adapt to climate change effects.
Building Codes and standard reforming	Housing challenges have also been resolved through reforming building codes and standards to increase affordability of housing to the urban poor (UN-Habitat, 2005). However, residents are not guided on how to build self-help houses to be affordable and yet maintain good structural integrity. This intervention provides an opportunity to introduce climate adaptive approaches to housing delivery which planners and builders will have to align with.

The intention of upgrading informal settlements is normally to address certain sustainable development goals such as eradication of poverty. However, there is need to maintain the status of sustainability by building resilience to natural disasters. One informal settlement upgrading program which many authors believe was a success is the Kampung Improvement Program (KIP) in Indonesia (Dianingrum, Faqih & Septanti, 2017). For its success it received the following awards: Aga Khan Award for Architecture in 1986, World Habitat Award in 1992 and UN habitat scroll of Honour in 2005 (Silas, 1992). Its success has been observed in the improvement of environmental quality and reduction of urban poverty (Dianinggrum et al., 2017). In the absence of resilience measures, these developments may revert back to how the settlement was before its upgrade (Hallegatte, 2016).

It is critical to understand how resilience can be built to informal settlements in order to incorporate the resilience practices in upgrading programs. This would ensure that the development gains, which come with upgrading informal settlements, are not reversed. The following section discusses resilience theory as a lens to understand informal settlements to identify opportunities for intervention that will keep these settlements functional and provide necessary services to residents.

2.4. Overview of Resilience Theory

External pressures have forced social-ecological systems to constantly change throughout history (Pelling, 2011). The pressure of climate change, which is the focus of this study, is slightly different due to the uncertainty involved in its effects, and in that it impacts humanity who are also contributing to these effects (Pelling, 2011). This uncertainty makes studying and addressing climate change effects the most critical challenge to help sustain livelihoods and wellbeing in urban areas. There are several general approaches highlighted in literature with the aim to address effects of climate change, and recently they relate to Resilience Theory, hence the exploration of this concept in this study.

Resilience Theory is understood as a framework for dealing with change (Davoudi, Brooks & Mehmood, 2013; Du Plessis, 2012a). Resilience is seen as the capacity of the system to adapt through time to change for the purpose of maintaining the system's functionality (Peres, Du Plessis & Landman, 2017). It is vital therefore, to understand the behaviour of systems through the lens of Resilience Theory to enhance their adaptive capacity to change. Over the past decades several publications have provided different views on the role of Resilience Theory, with all in agreement that it must play a role in assessing the preparedness of certain systems or entities to respond to and recover from natural and man-made threats (Davoudi et al., 2013).

The background of Resilience Theory has been discussed in literature by several authors (Berkes, 2007; Djalante, Holley & Thomalla, 2011; Folke, 2010; Masnavi, Gharai & Hajibandeh, 2019) claiming that Holling (1973) was the first to introduce the term in the field of ecology. Berkes (2007:286) for example wrote, "Originally developed as an ecological concept, resilience is being applied to coupled human-environment systems." Folke et al. (2010), supporting the claim, also state that resilience was firstly introduced as a concept for understanding the capacity of ecosystems to maintain their original state even when exposed to external disturbances (Folke et al., 2010).

However, there is evidence that the term 'resilience' was used for the first time by Francis Bacon as a scientific English term in natural history in 1625 (Alexander, 2013). Manyena, O'Brien, O'Keef and Rose (2011) support that this term existed before it was introduced in ecology in 1973. According to Manyena et al. (2011), the term resilience comes from a Latin term 'resilire, lesilio' for 'bounce' from the classical times. Alexander (2013) has traced the meaning from several ancient writings to have meant 'leaping', 'jumping' or 'rebounding', but the meaning evolved with time (as discussed in detail in Alexander, 2013) until the scientific meaning and use of resilience in English by Bacon, found in his writings 'Sylva Sylvarum'. The 'serious' use of the term 'resilience' appears in mechanics thereafter in 1858, to describe the strength and ductility of steel, before its adoption by Holling in ecology, which many authors recognised.

Davoudi et al. (2012) state that resilience and systems thinking started being explored in the 1960s along with the rise of 'systems thinking'. The concept branched into Social Sciences in the 1970's (Zolli & Healy, 2012). However, Alexander (2013) traced this transition (natural ecology to human ecology) to have occurred at the end of the 1990s. Either way it is established in literature that resilience migrated from natural sciences and only got to be translated to social sciences at a later period. In human ecology, the idea now was that humans adapt to changes in their environment. Multiple meanings of resilience arose thereafter, and resilience theory has afterwards been explored in different disciplines such as mechanics, psychology, ecology (Alexander, 2013; Hassler & Kohler, 2014; Hollnagel, 2014), engineering (Gunderson, 2000), social, urbanistic and sustainability studies (Bigolin, Bussular & Silvar Filho, 2020). Resilience thinking has further been used in several different aspects in urban literature, such as ecosystem services, spatial planning, planning action, land use, urban hazards and natural disasters, amongst others, as categorised by Masnavi et al. (2019). There are several studies which have also explored climate change resilience in cities (Adgar, Arnell & Tompkins, 2005; Davoudi et al., 2013; among others). However, they have not explored the evolutionary nature of specific subsystems of cities such as settlements, especially those mostly impacted by external disturbances.

The use of the term in different disciplines as, however, brought confusion in its interpretation and uses (Alexander, 2013) and its practical application in the built environment is still questionable. Hassler and Kohler (2014) state that there is no single definition of resilience as it has evolved over the past 40 years. Resilience is defined differently depending on the context in which it is being used (Table 2.6). It is sometimes imprecise and contradictory, which Vale (2005) believes makes it an overloaded concept that may collapse and become meaningless because of its many meanings (Hassler & Kohler, 2014). On the same note, Rose (2007) states there is a risk of the concept becoming a vacuous 'buzzword' due to its overuse in literature. On the positive side, resilience is also seen as a unifying concept and future interdisciplinary bridge (Hassler & Kohler, 2014).

This study will focus on resilience in relation to the built environment: "man-made building and infrastructure stocks which constitute the physical, natural, economic, social and cultural capital" which also corresponds to the definition of a socio-ecological system (Hassler & Kohler, 2014:120). In Hassler and Kohler's own words, "the concept of resilience offers a means to address the long-term evolution of the built environment and to explore implications of changing conditions on the efficacy of different approaches to planning, design, operation, management, value, and governance" (Hassler & Kohler, 2014:121). The key question that should be addressed is how urban systems can be planned and designed to become more adaptive to change (more especially change with uncertainty like climate change).

Table 2.6: Different context-specific definitions of resilience

Reference	Context	Definition
Gere & Goodmann (2009)	Physical systems (materials)	Ability of a material to absorb and release energy, within the elastic range
Holling (1973)	Ecological systems	Measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between state variables
Walker et al. (2004)	Ecological systems	Capacity of a system to absorb a disturbance and reorganize while undergoing change while retaining the same function, structure and identity
Carpenter et al. (2001)	Socio-ecological systems	Magnitude of disturbance that a system can tolerate before it transitions into a different state that is controlled by a different set of processes
Adger (2001)	Social systems	Ability of communities to withstand external shocks to their social infrastructure
Masten (1990)	Individual	Process of capacity for or outcome of successful adaption despite challenging or threatening circumstances
Bruneau et al. (2003)	Disaster risk management	Ability of social units to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities that minimize social disruption and mitigate the effects of future earthquakes
Hollnagel et al. (2006)	Resilience engineering	Ability to sense, recognize, adapt and absorb variations, changes, disturbances, disruptions and surprises
Harnel & Valikangas (2003)	Organizational	Resilience refers to the capacity to maintain continuous reconstruction

Sources: Bhamra, Dani & Burnard (2011) and McAsian (2010)

Meerow et al. (2016) in their review of 25 different definitions of urban resilience, indicated three pathways to a resilient state as: persistence, transition, and transformation. Persistence talks of resisting disturbance and attempting to sustain the function of the system, which is the type of resilience Holling termed as engineering resilience (Chelleri, 2012). There are other authors who acknowledge the importance of sustaining the state of a system but further refer to the ability to incrementally adapt (transition) or even transform (Brown et al., 2012; Folke et al., 2006; Romero-Lankao & Gnatz, 2013) which agrees with the pathways by Merrow et al. (2016). Ribeiro and Goncalves (2019) also conclude that there are four pillars in which urban resilience is based on: resisting, recovering, adapting, and transforming. The system's ability to absorb, self-organise (related to the recovery of a system), adapt, and transform is referred to by Tong (2021) as the main characteristics of social-ecological resilience, and by Dastjerdi et al (2021) as system behaviour attributes. These characteristics or pillars or pathways, as different authors call them, can be understood as overarching the urban resilience characteristics of diversity, network modularity, redundancy, connectedness, tightness of feedback, and robustness, among others. The overarching abilities and the characteristics are both expected in a resilient system.

2.4.1. The Types and Perspectives of Resilience

There are three common approaches dealing with the resilience concept in social-ecological systems namely: engineering resilience, ecological resilience, and evolutionary resilience (Davoudi et al., 2012), with the first two dominating literature and claimed to be foundational (Peres, 2016), and evolutionary resilience being recent with its exploration in literature growing rapidly. These different approaches are also referred to as different 'types' of resilience or different ways (meanings) in which resilience is understood (Brand & Jax, 2007; Davoudi et al., 2012) or different ways resilience is interpreted (Holling & Gunderson 2002).

Resilience Theory has evolved according to the different ways the concept has been interpreted and used over the years. Defining and measuring resilience may therefore differ depending on the perspective from which the concept is discussed.

2.4.1.1. Engineering resilience

The first perspective is that in which resilience is described as 'bounce back' (Brand & Jax, 2007). In this context, resilience is considered as a recovery from a negative perturbation (Zolnikov, 2019) and a return to the state before the perturbation, with Brand and Jax (2007) describing it as the time it takes to attain the state of equilibrium after a disturbance. This definition gives a sense of coping with the effects of changes while the system stabilises. This is the meaning of resilience focusing on maintaining stability closer to an equilibrium state after experiencing an impact, termed by Holling (1996) as engineering resilience. The disturbances referred to could be natural disasters, or social upheavals, among others (Davoudi et al., 2012). The measure of resilience here is resistance to disturbance and how quick a system returns to equilibrium (Davoudi et al., 2012). Peres (2016) suggests that the current focus in dealing with change in the built environment is through this anti-adaptive 'bounce back' attempts to keep the city stable in its function in the event of a disturbance.

Reduction and reversing of effects (through a return of the system to equilibrium), as well as persistence, is clearly at the centre of this approach, which can possibly be insufficient for addressing evolutionary change in living systems. Engineering resilience is, however, still a very useful approach and a good starting point in addressing change, but it requires systems whose dynamics are closer to equilibrium, such as hard infrastructure, according to Peres (2016).

From the perspective of engineering resilience, resilience keeps systems functioning in their normal state through mitigation and building capacity for 'healthy adaptation' when thresholds within the system have been crossed (Zolli & Healy, 2012).

2.4.1.2. Ecological resilience

Folke (2006) highlights a different view, proposing that change fluctuates, especially in living systems. This approach is called ecological resilience. Advocates of this approach understand that ecological systems are complex systems which exist in forms distant from equilibrium. These systems are characterised by qualities such as persistence, adaptability, and unpredictability, and goes through cycles of change which entails both slow and cumulative change and unexpected and disruptive changes (Du Plessis, 2012a). In this context, resilience is interpreted by Du Plessis (2012a) as "the ability of a system to move through periods of episodic change (promoted by an external disturbance or increased internal rigidity) without crossing a threshold into a different stability regime (and thus losing functional identity)". Holling introduced this idea of thresholds as he had an understanding that natural systems have a high capacity to absorb change without altering, but there are limits which can be passed where the system can be changed to another condition (Holling, 1973).

Ecological resilience accepts the existence of multiple equilibria and ability of a system to shift to an alternative stability domain (Davoudi et al., 2012). Holling defined ecological resilience as "a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" (Holling, 1973:14). Focus is on maintenance of function and form through improvement of the capacity of the system to resist disturbances. Remaining within a regime is also emphasised in this definition (Du Plessis, 2012a; Holling, 1973; Peres, 2016).

In reference to the two types of resilience, systems under disturbance will either bounce back (engineering) or bounce forward to a new state (ecological) (Davoudi et al., 2012; Davoudi et al., 2013). Alexander (2013) supports this view as he describes Holling's seminal papers as discussing equilibrium in ecological systems. Davoudi et al. (2012) argue that engineering and ecological resilience both rely on systems equilibrium in their definitions and proposes a view of resilience for systems that are far from equilibrium.

2.4.1.3. Evolutionary resilience

The third form of resilience, as proposed by Davoudi et al. (2012), opposes the idea of equilibrium and arises from the understanding that aspects of a social-ecological system may change, adapt, and transform post disturbance by collapsing or regenerating to a state which can increase the capacity of a system to survive (Walker & Salt, 2012). The system may not return to normality. Sub-systems in this case can collapse, but the core functionality of the whole system can be maintained. This meaning implies transformation in systems and has been termed as evolutionary (Davoudi et al., 2012). It promotes a partnered relationship between nature and humans as it sees these systems as interdependent. Resilience Theory in this perspective can change urban perspectives "from equilibrium-managed to thriving and dynamic social-ecological systems" (Peres, 2016:87). To achieve this, Du Plessis (2011) suggests that dynamic habitats may demand for some aspects of life to collapse to give room for new life to grow. Evolutionary resilience is a relevant approach to deal with future uncertainties such as the effects of climate change, since this type of resilience understands systems as constantly changing (Tyler & Moench, 2012).

In this viewpoint, adaptation and transformability are seen as essential in maintaining the resilience of a system, which contrasts with the idea of paired adaptation and mitigation as discussed by Zolnikov (2019). This idea arose after a paper written by Walker et al. (2004) which explored the relationship between resilience, adaptability and transformability (Folke et al., 2010). In this paper, resilience is defined as "the capacity of a system to absorb disturbance and reorganise while undergoing change so as to still retain essentially the same function, structure, identity, and feedback" (Walker et al., 2004:4). Adaptability and transformability have been contrasted by Walker et al. (2004) stating that adaptability is "the capacity of actors in a system to influence resilience", while transformability is "the capacity to create a fundamentally new system when ecological, economic or social structures make the existing system untenable" (Walker et al. 2004:5). Transformation at smaller scales triggers resilience at larger scales, "while the capacity to transform at smaller scales draws on resilience at other scales" (Folker, 2010). In transformation, collapse is seen to bring benefits or opportunities of creating a better system. To attain resilience of a system, therefore, the capacity of that system to adapt and transform must be developed.

Folke (2006) presents a different schema. The three types of resilience proposed by Folke, along with their characteristics are summarised in Table 2.7. The understanding of 'engineering resilience' by Folke (2006) is similar to that discussed above, with the focus being on the rate a system takes to return to former state/ equilibrium. Folke (2006) however, introduces another type of resilience termed as 'social-ecological resilience with similar characteristics of transformation as the 'evolutionary resilience' discussed by Davoudi et al. (2013). Social-ecological resilience focuses on the capability of a system to reorganise and the degree a system can build the capacity to learn and adapt (Folke, 2006).

In the discussion of resilience, it is also important to understand that resilience desirable for one may not be desirable for others (Helfgott, 2018). The different types of resilience discussed above may not be desirable in some systems or subsystems. Undesirable resilience, also referred to as "perverse resilience", has been defined by Phelan et al. (2013:202) as "resilience within a system that is undesirable to the extent that it is socially unjust, inconsistent with ecosystem health or threatens overall system viability". It proposes that the resilience of one subsystem at times threatens the wellbeing of the whole system (Dunstan, 2019). This means breaking the resilience of unsustainable social ecological systems or dysfunctional systems may be important in some cases with the understanding that resilience is value-neutral (Dornelles et al., 2020).

Table 2.7: Types of resilience

Resilience Concept	Characteristics	Focus on	Context
Engineering	Return time, efficiency	Recovery, constancy	Vicinity of a stable equilibrium
Ecological	Buffer capacity, withstand shock, maintain function	Persistence, robustness	Multiple equilibria, stability landscapes
Social-ecological	Interplay disturbance and reorganization, sustaining and developing	Adaptive capacity, transformability, learning, innovation	Integrated system feedback, cross-scale dynamic interactions

Source: Folke (2006)

From the above discussion, resilience is generally about how we respond to change which is what all advocates of this concept are addressing. Adaptation and transformation are approaches towards attainment of desirable resilience. Resilience theory is useful for assessing the preparedness of complex, adaptive, living systems such as social-ecological systems to respond to and recover from threats (Carlson et al., 2012). The next section reviews the nature of these systems and their resilience.

2.4.2. Overview of resilience of social-ecological systems

The concept of 'social-ecological systems' emerges from the understanding of an interplay between nature and society, but it is understood differently across many disciplines within humanities, social sciences and the natural sciences (Folke et al., 2016). The social refers to the human dimension, which includes economic, political, technological and cultural. The ecological aspect refers to the biosphere, which is a term referring to the global ecological system including different integrated living systems (humans and their actions included) and their integration (Folke et al., 2016). Socio-ecological systems emphasise the co-relationship between the biosphere and people, communities, economies, societies, and cultures. Clark and Munn (1986) and Folke et al. (2010) agree that the social aspect is embedded within the biosphere and shaped, depends on, and evolves with it.

The social and ecological aspects cannot be separated since humans are dependent on the resources and services of the biosphere, and the ecological systems cannot be understood without considering human influence on them as humans contribute to their changes and capacity. Folke et al. (2016) state that if sustainability is the focus, these links cannot be ignored, as the social and ecological aspects are connected and coevolve, shape and are shaped by each other (Folke et al., 2016). "Humans operate in a legacy of social-ecological interplay, directly or indirectly, consciously or unconsciously, shaping the capacity of the biosphere, and our options and opportunities for development. And if human well-being is a central goal of sustainability, its dependence on a resilient biosphere has to be accounted for, a necessity that has become more and more obvious" (Folke et al., 2016:46).

Social-ecological systems are defined as "complex adaptive systems, where agents interact in unplanned and unpredictable ways" (Folke et al., 2016). Du Plessis (2011:5) clarifies that the systems are complex for their diversity and multiple interconnected elements, and adaptive as they have "capacity to change and learn from experience." Interactions of the different systems and their agents have been well explored in literature and they give rise to the properties of social-ecological systems. The interactions of the agents give birth to patterns at a broader scale which again influence the interactions of the agents, and the system as a whole, making the properties of complex adaptive systems to change and form properties of the whole (Folke et al., 2016). These interactions make the system self-organise spontaneously into collective structures (Du Plessis, 2011) to give rise to new properties of the newly formed collective structures. These newly formed properties cannot be determined from the individual agents prior to the interactions. This concept is referred to as emergence.

In the context of this study, cities are considered as social-ecological systems consisting of physical components, as well as “human mental constructs like norms, values and rules, as well as intangible actors like governments and businesses” (Du Plessis, 2012a). This understanding of cities further suggests that the properties to consider in the discussion of sustainability of cities should be properties which constitute resilience thinking - resilience, adaptability, transformability, connectivity, and diversity (Du Plessis, 2011).

Folke et al. (2010) have defined resilience of social-ecological systems in terms of maintenance of the same identity of a system through the absorption of disturbance. In this case resilience does not focus on returning a system back to its normal state, but as an ability of a social-ecological system to change, adapt or transform in response to disturbance (Carpenter et al., 2005). Walker et al. (2006) have listed five heuristics of social-ecological resilience which describe patterns of sudden change: adaptive cycle, panarchy, resilience, adaptability and transformability, with the first two describing dynamics in systems, and the last three being properties of systems. These can also be described as characteristics of social-ecological resilience which should be understood to create resilient systems.

There is currently a need to manage threats in cities, and that requires a better understanding and accurate definition of resilience (Masnavi et al., 2018). A framework of resilience for addressing change has been put forward by Holling (1973) and further developed by Walker and Salt (2006), emphasising the relationships between social and ecological systems (Floke et al., 2010). The goal is to create a sustainable urban system, and to achieve that, the identified principles of resilience thinking should be explored in application. The understanding of resilience theory in relation to urban systems (not only in ecological systems) is vital for proper application of the framework aimed at addressing change in urban systems.

2.4.3. Resilience Thinking Concepts

The general purpose of resilience thinking is to better understand and manage change in and the dynamics and behaviour of a living system. Resilience Theory has introduced concepts such as thresholds and stability regimes, episodic change (the adaptive cycle) and cross-scale change (panarchy) (Du Plessis, 2012) which should be explored to understand the behaviour of systems to effectively address changes occurring within them. These concepts function within socio-ecological systems, as discussed in the following subsections.

2.4.3.1. Thresholds and stability regimes

The discussion in this section relates to the stability regimes in which systems may exist, the state of the system, as well as the system's position in relation to the thresholds of the stability regime (Du Plessis, 2012a). The understanding is that a system can take different states within the same stability regime and still retain the same structure, function, and feedback, unless it crosses a threshold to a new state space where feedback, function, and structure changes (Walker & Salt, 2006). The change in state which shifts the system around is determined by change in the values of key state variables (Du Plessis, 2012a). This gives a sense that understanding and handling the state variables controls the state position of the system, as well as its rigidity and capacity to adapt or transform. A resilient system is one that keeps away from equilibrium within the same state space and avoids crossing a threshold unless transformation is necessary to keep the system functional. This can be achieved through managing the relationship between a threshold and system state, in the words of Walker and Salt (2006:118): "moving thresholds, moving the current state of a system away from a threshold, or making a threshold more difficult to reach". These are three ways of controlling resilience as proposed by the authors.

The concept of stability regimes has originally been defined in the context of ecosystems, with an example of a landscape dominated by a group of species given by Du Plessis (2012a). The author states that such a stability regime has clear descriptors and functions which give its identity, as well as variables contributing to its movement within the regime or across a threshold. It is vital to identify the same (stability and variables) in urban systems to understand their resilience. Du Plessis (2012a:499) has identified the equivalent of ecosystem variables in urban systems as: "population and spatial density, level of formality, income per capita, and governance capacity." For instance, urbanisation causes a high demand for affordable housing, causing a change in spatial urban form with the development of slums. Density, tenure and building form are some identified variables that can tip this system regime to another (Du Plessis, 2012a). All cities have initially started as rural areas, but later transformed through a series of different regimes, each with a different urban structure. In Eswatini, agricultural land at Malkerns has recently shifted to upmarket residential apartments which is a totally different regime. It crossed a threshold of land use and economic status. In further examples, thresholds of formality, density, security, and economic status were crossed in the development of the inner city Hillbrow area of Johannesburg from extreme informality to luxurious skyscrapers and then to another type of informality. However, Du Plessis (2012a) questions the point of change to a different regime in settlements e.g. formal to informal settlement, and identification of variables which push an urban system to other different system states or regimes. Such knowledge can help in controlling the system state to a desired state or else a new stability regime.

2.4.3.2. Adaptive cycle

The structure and function of complex adaptive systems is dynamic and has periods of growth, destruction and decay which tends to vary across scales and time (Angeler et al., 2015). The structure and functions of systems are understood to go through four phases of change which Holling (1986) calls an “adaptive cycle”, as visualised in Figure 2.2 below. This concept was introduced by Holling to describe phases of dynamic change in ecosystems - exploitation (or growth), conservation, release (or creative destruction) and reorganize (Gunderson & Holling, 2002), and it is at the centre of social-ecological resilience (Wilkinson, 2011). This has proved to be a useful concept and it has gained interest from several authors who have explored it (Du Plessis, 2012a; Davoudi et al., 2013; Gunderson & Holling, 2002; Pendall et al., 2010; Peres, 2016). Du Plessis (2012a) sees this as one of the key themes of resilience thinking.

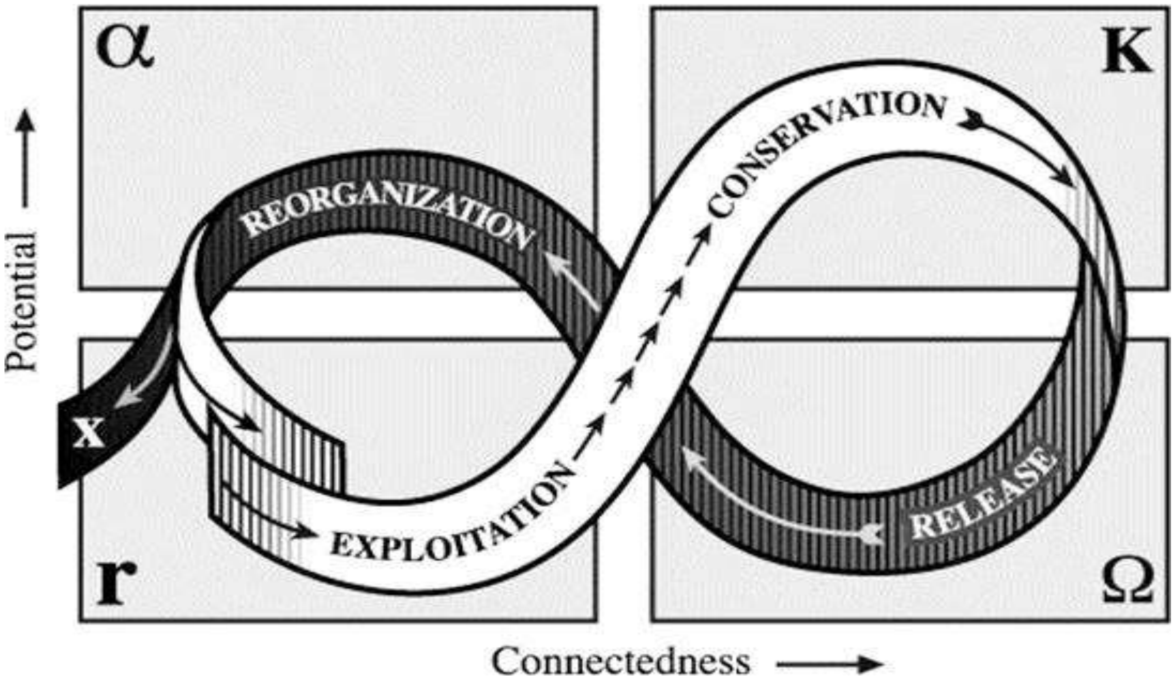


Figure 2.2. Adaptive Cycle (Resilience Alliance, 2010)

A. The growth phase (r) (exploitation)

The growth phase is characterised by the “rapid accumulation of resources (capitals), competition, seizing of opportunities, rising level of diversity and connections as well as high but decreasing resilience” (Davoudi et al., 2013:152), and a stage in which “rapid colonisation of recently disturbed areas is emphasised” (Gunderson & Holling, 2002:33). In this phase, components are weakly interconnected according to Du Plessis (2012a). Opportunities and resources are heavily exploited which creates the rapid growth rate denoted with “r”, which then begins to slow down into the conservation phase (k) as resources are stored and used for system maintenance (Davoudi et al., 2013).

B. Conservation phase (k)

Davoudi et al. (2013) state that this phase is characterised by “stability, certainty, reduced flexibility, and low resilience”. Gunderson and Holling (2002:33) explain that there is emphasis on slow accumulation and storage of energy and material in this phase, and in this stage, components are more strongly interconnected. Du Plessis (2012a) points out that as much as the system becomes more stable, that stability comes at a ‘cost of diversity and reduced resilience’. The longer a system remains in this phase the easier it can be shifted to the release phase by perturbation which creates a crisis (Peres, 2016). The systems become more rigid and capable of being destroyed as a result of its low resilience.

C. Release phase (Ω)

The accumulated capital is released and the system collapses as a result of either an external perturbation such as natural disasters, or perturbation caused by long-term internal pressure such as systemic poverty. This is said to be a rapid process as the system releases the energy accumulated in the previous phase.

D. Reorganisation phase (α)

The system then enters the reorganisation phase (α) after the system has been disrupted. This is a time of opportunity: innovation, restructuring, experimentation, with high resilience (Pendall et al., 2010). In this phase, a system may tip into a different (unpredictable) regime with different processes or can maintain the original regime which is a predictable trajectory (Allen et al., 2014).

There are two major phases (or transitions) which are exhibited by the adaptive cycle, namely the ‘foreloop’ and the ‘backloop’ (Resilience Alliance, 2010). The foreloop is from the exploitation to conservation and it is the slow, incremental phase of growth and accumulation. In this phase connectedness and stability increases. The backloop is from release to reorganisation and it is the rapid phase of reorganisation leading to renewal.

Berkes et al. (2003:16) gives a forest as an example of the manner the cycle functions, stating that a forest grows and matures, which may be followed by destruction through fire which releases nutrients that as well fosters a new cycle. The ability of a system to move through the phases of the adaptive cycle (without shifting to a different regime) ensures its resilience. A question raised is whether a settlement as a complex system is able to move through the phases of the adaptive cycle? Walker and Salt (2006) suggest that a system that is able to do so has an adaptive capacity. The authors further speak of three characteristics determining the adaptive capacity of an ecosystem - response diversity, connectedness, and tightness of feedback.

The application of an adaptive cycle in urban systems can be best understood through an example, such as that of Hillbrow as discussed by Du Plessis (2012a). This neighbourhood has gone through several phases within the adaptive cycle. The change started with the omega phase, the discovery of gold which developed new economic potential in an agricultural system. Competition for real estate, housing, and other developments occurred as the system shifted to the alpha phase. The structure of the system was formalised as a high-density neighbourhood created with a specific form in the r-phase; the created typology was established and difficult to change at its peak, which made adaptation to a collapse in the socio-economic aspect a challenge in the k-phase. This made the structure rigid and eventually a social and built infrastructure collapse occurred. The author further states that at the time, new potential was being released, meaning the system was shifting to the omega phase once again.

The adaptive cycle, however, focuses on understanding a system at a single scale, yet all systems exist and function at multiple scales of space, time, and social organisation. The interactions across different scales are critical in understanding the dynamics of the system at any focal scale. The dynamic interactions of the different hierarchically structured scales is known as ‘panarchy’ (Gunderson & Holling, 2003). The panarchy concept is discussed in the next subsection.

2.4.3.3. Panarchy

The concept of ‘panarchy’ was introduced by Holling and Gunderson (2002) to provide a framework for theory which deals with cross-scale dynamics in natural and social systems (Du Plessis, 2009). Allen et al. (2014:578) states that this framework “characterises complex systems of people and nature as dynamically organized and structured within and across scales of space and time”. It explains “the interplay between change and persistence, between the predictable and unpredictable” (Gunderson & Holling, 2002:5). The concept of the panarchy was also introduced to bring to attention the evolutionary nature of systems. This concept uses a different type of hierarchical approach as control is not only from larger systems (top-down) but may also occur from smaller scale (bottom-up) processes. The dynamics and application of panarchy is discussed in the following points.

A. Dynamics of panarchy

Du Plessis (2009) states that change within the panarchy is a constant phenomenon at each scale of the system in which there are different survival strategies which drive different types of agent behaviour. Adaptive cycles in each level interact with each other, which drives change across levels. Cross scale linkages are emphasised with processes at one scale affecting processes at other scales to influence the overall process of the system (Allen et al., 2014). Each scale has a certain structure pattern having unique processes driving different patterns at different scales, with the interactions between pattern and process (in each scale) driven by positive feedback. The linkages in cross scale components relate to 'within-scale system position' within the adaptive cycle. For instance, a system at the omega phase can have its processes affecting larger scales. The process of renewal and collapse (adaptive cycle) differs from the traditional hierarchy. This concept suggests that the phases of the adaptive cycle are not sequential or fixed, for instance, from the reorganisation stage a system may enter any other stage, as it operates in "panarchical" cycles (a series of nested adaptive cycles) one nested within another, and may skip other stages (Walker & Salt, 2006; Davoudi et al., 2013). This occurs at multiple scales "from small to large, at different speeds from slow to fast, and in various time frames from short to long" (Davoudi et al., 2012). This releases the efficiency and innovativeness of the system. Walker and Salt (2006) state that a system cannot move from the release phase back to conservation phase, but it can move freely to all other phases.

Du Plessis (2009) describes the panarchy as being gradually constructed as potential builds up at one level until the system tips over the threshold which allows the establishment of a slower and larger level. The panarchy may collapse in a case where all the system levels simultaneously enter the breakdown phase of their different adaptive cycles.

According to Davoudi et al. (2012), this panarchy model of adaptive cycle is where the evolutionary meaning of resilience is mainly rooted. Resilience is viewed as a continuous process rather than a fixed concept. This cycle may bring interesting views when looking into sustainability and resilience in cities viewed as social-ecological systems.

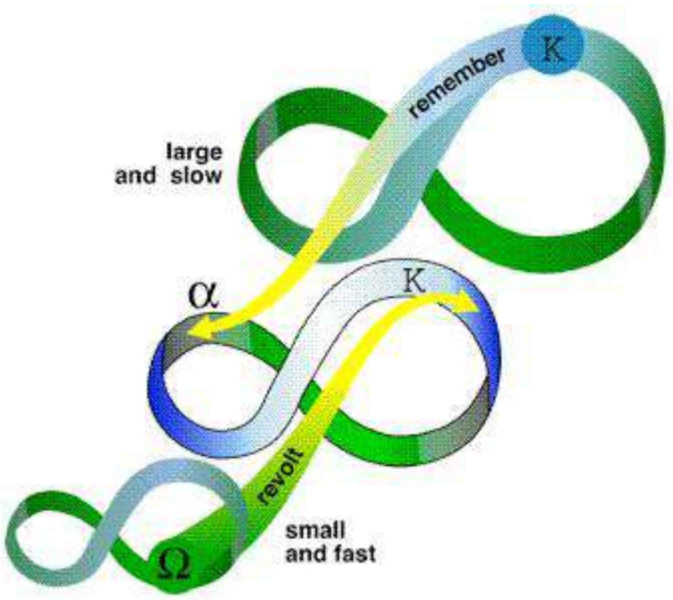


Figure 2.3. The panarchy model of adaptive cycle (Gunderson & Holling, 2002)

The panarchy concept is linked to resilience. The adaptive systems affect resilience as disturbance creates feedback which either tries to return the system to equilibrium or allow for change. Literature, according to Allen et al (2014) has used panarchy in different ways - as a framework for managing change, identifying scales, and mostly identifying aspects of resilience. The theoretical aspect of panarchy, and linkages between social and ecological systems to enhance resilience, are other areas of focus observed (Allen et al., 2014).

B. Application in urban systems

Panarchy has been used in urban studies addressing discontinuities in urban systems - suggesting that urban systems are compartmentalized into discrete scales which are separated by thresholds. The concept has been translated in urban systems to explain city growth. In such, small cities claimed to grow faster than average cities, and larger cities growing slower than average cities (Eason & Garmestani, 2012).

The translation of panarchy in urban systems further helps in highlighting the relationships and interactions between urban components which may influence development. These interactions of components or individual agents produce ripple changes across different scales of the whole urban system (Du Plessis, 2009). These interactions in adaptive systems occur until some workable order, which enables them to survive, connect with their environment and reproduce in never-ending adaptive cycles of growth, accumulation, restructuring and renewal, is figured out (Eason & Gamenstani, 2012).

2.5. Urban resilience

Since the industrial revolution, urban areas globally are facing rapid population growth as a result of labour market shift forced by employment opportunities created in these areas(UN, 2014). Urban population in developing countries alone is expected to increase to 5.1 billion by 2050 (UN, 2012). As cities continue to expand spatially, and grow in population diversity and complexity, their vulnerability to future extreme events and disasters caused by climate change, among others, continues to grow as well. It is evident that urban areas are experiencing rapid change, which puts pressure on urban systems that governments are struggling to manage. These urbanisation dynamics and projected effects of climate change exert even more pressure on urban communities and their governance (Ribeiro & Goncalves, 2019). How to deal with change in cities is a concern that literature is still attempting to address. According to Du Plessis (2012a), economic uncertainty, peak oil, and the natural disasters that struck urban areas in certain countries, such as the USA and Japan, prompted interest in addressing the resilience of cities to contribute to their sustainability. Masnavi et al. (2019) state that in the city context, more research has been conducted on social resilience compared to spatial structure. It is therefore critical to understand the background and application of resilience in urban areas to ensure the achievement of sustainable goals.

In exploring the background of Resilience Theory, four levels are identified in its evolution in relation to its integration with social sciences and urban planning literature (Masnavi et al., 2019). The first stage relates to its appearance as an ecological concept as discussed by Holling (1973). The second stage is the time when resilience gained interest in the social sciences as discussed in Walker, et al. (2004). The third stage is when cities were viewed as social-ecological systems in addressing their resilience; a stage where Folke (2006) explored the idea that humans are part of urban systems, and the integration of humans and ecological factors within urban systems. Resilience thinking was at this stage used in social-ecological systems such as cities (Walker & Salt, 2006). The last and current stage, explores the principles of the concept of resilient cities, emphasising the coexistence of urban systems with environmental hazards as well as a holistic approach to resilience in urban systems (Masnavi et al., 2019). Sustainability strategies are now developed in view of interactions between humans and ecological factors, which is currently studied in urban resilience thinking.

Resilience theory in a city has been defined as “an approach to understanding and determining where the strengths and weaknesses within the urban network lie in relation to tangible, as well as intangible reserves of urban capital” (Peres et al., 2017:693). The ‘tangible’ term refers to the spatial aspect of the city, and the ‘intangible’ refers to the social, economic and cultural aspects of the city. According to Peres et al. (2017:693) the key question which should be addressed is: "how do we strengthen the tangible and intangible capital reserves within the urban system and subsystems in order to transition the city towards the healing goals and a dynamic regenerative state that is proposed by sustainability?" This will ensure the maintenance of the city's desired function, as Walker and Salt (2012) state - urban resilience is about the maintenance of a city's (as a SES) purpose and integrity in the event of disturbance. This can be through transformation of the system (city) to maintain its functional integrity (Gotham & Campanella, 2010). Through integration of different definitions of urban resilience, Meerow et al. (2016) came up with a new definition of resilience, "Urban resilience refers to the ability of an urban system - and all its constituent social-ecological and socio-technical networks across temporal and spatial scales - to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity." All the authors emphasise the maintenance/sustainability of urban function and integrity as a goal of urban resilience. From Meerow et al. (2016), absorption, adaptation, and transformation seem to be the pathway towards achieving that goal.

2.5.1. Urban Resilience and Sustainability

Resilience is considered necessary to achieving sustainability of cities, hence there is a correlation between the two concepts of 'resilience' and 'sustainability'. The connection between resilience and sustainability has been explored in an attempt to find measures for addressing unexpected changes and interruptions in urban context by several authors, with the aim of unravelling their commonalities and differences to determine whether they complement each other, or if they are two separate concepts (Ahern, 2011; Dovers, 1996; Marchese et al., 2018; Zhang & Li, 2018). Given the catastrophic pressures, such as climate change, which affect these urban systems, it is vital to translate the general resilience of these systems and further transform them to meet sustainability goals, as according to Du Plessis (2012a), very little research has been done in systems such as cities.

Kuhlicke, Kabisch and Rink (2019:19) highlights that sustainability and resilience are both underpinned by ''a strong concern about disturbances and potentially unstable future developments''. However, they differ in the way they address disturbances. Since disturbances are no longer seen as negative events associated with destruction, stress, and loss, but as a 'window of opportunity' for transformation towards sustainable development and conditions that are less vulnerable to change (Kuhlicke et al., 2019), resilience viewed as a pre-condition for sustainable urban development. Resilience accepts the disturbances and catastrophic events, prepares for them and further learns from them to attempt to reduce their impact, and may further transform the system towards the desired sustainable state.

Sustainability and resilience are understood as normative concepts. However, Kuhlicke (2019) states that their normativity differs in that sustainability has a strong normative expression, while the normativity of resilience is more opaque. Meerow (2016) states that resilience has evolved from being a characteristic of a system to more of a normative position. Resilience is a means to achieve set sustainability goals and maintaining the capacity of the system to continue to provide what is required to support sustainability goals according to Peres et al. (2017). Resilience Theory provides an opportunity to understand sustainability as a normative position which is based on the goal to restore connections in the living system by healing and then regenerating social-ecological systems (Peres et al., 2017:692). Leichenko (2011) confirms that the idea that resilience contributes to sustainability is now well accepted in literature. The definition by Brown et al. (2012:534) aligns with this idea as it defines urban resilience as "the ability not only to maintain basic functions but also to improve and prosper." This understanding gives a sense that resilience of a system can be determined post identification of normative goals (such as sustainability goals) for that system, which can then be met and maintained (made to persist) through identification of a capacity of the system to maintain these goals. It is therefore impossible in this case, where resilience takes a normative position, to determine the resilience of a system if the goals or targets are unknown. Further understanding in this view is that resilience can be measured differently in different systems with different sustainability goals.

The concepts have been compared based on space-time dimension. They both speak of the future, but urban resilience is 'opaquer' concerning its future orientation, while sustainability is more straightforward. Resilience suggests ways of preparing for uncertain dynamic changes, while sustainability is clear on what needs to be done, which is meeting specified human needs without depleting environmental capital. Sustainability discusses the future in the long-term (current needs and future generation), while resilience prepares for disturbances that can occur at any time (Kuhlicke et al. 2019).

Peres et al. (2017), argues that the aim of urban sustainability is not only about meeting human needs and protecting natural systems, but also to ensure that the functional integrity of cities is well maintained. This ties resilience with the qualities of a sustainable city due to the assumption that a social-ecological system (city) which is resilient also supports our quality of life (Walker & Salt 2006). The qualities of a sustainable city include health, safety and security, mobility, and other qualities and relationships giving rise to a thriving and regenerative urban system in which the relationships within and between social and ecological systems are healed and renewed (Hes & Du Plessis, 2014). This gives a sense that in the absence of resilience, the system may degenerate and fail to maintain the intended function of the system, leading to unsustainability. A city is considered sustainable because of the existence of resilient qualities in that system.

It can be concluded that the new objectives of urban sustainability accept change as unavoidable, and instead of resisting or reversing it, phase changes should be managed for the system to maintain its functional integrity and avoid shifting to another stability regime, or avoid disturbance from crossing to other larger systems (Du Plessis, 2009). This means the capacity of the system to experience disturbances should be managed to ensure the function of the system, its structure and identity are maintained (Du Plessis, 2009). This is already the function of resilience. Quoting from Du Plessis (2009:311), the objective of urban sustainability research should shift to:

> *"a) study, understand and monitor the thresholds and boundaries that define the preferred stability regime of the urban SES and the variables that influence them; and*
>
> *b) to study and understand the dynamics that have given rise to undesirable phenomena, in order to find the most effective leverage points at which to intervene to keep the urban SES within a desirable stability regime."*

This simply confirms that resilience should be studied along with sustainability. Sustainability goals should be clearly defined along with the desired stability regime in which the system should exist for proper functioning. Resilience would then be built into the system to maintain the function by keeping the system within the desired stability regime or shifting to a different desired stability regime. Considering this understanding, therefore, in the study of sustainability, the two terms should be tied together as sustainability is attainable through resilience.

2.5.2. Urban Resilience and Regenerative Development

A complex adaptive system offers an opportunity to create a better and more sustainable world by taking advantage of the released potential from a collapsed rigid system (in the release phase of an adaptive cycle), and regenerative development is required for that to be possible (Du Plessis, 2011). According to Du Plessis (2011), resilience and adaptive capacity may help humanity to survive the Great Disruption, but it is the regenerative capacity of the global social-ecological system which will make use of the changed environment and create a life-enhancing world, with its restoration capabilities. The characteristics of resilient systems can be used to leverage regenerative development goals (Du Plessis, 2011). Meaning the regenerative development goals of a social-ecological system should be defined, and then resilience will act as a pathway towards attainment of those goals.

The relationship between resilience theory and regenerative development comes from the idea that resilience does not only aim for the continued health of a system, but also its future evolution (Du Plessis, 2012b), a principle best understood within regenerative development theory. One of the key premises of regenerative development is quoted in Mang and Haggard (2016:10) stating that “every living system has inherent within it the possibility to move to new levels of order, differentiation, and organization.” According to the authors, this comes from the claim that all living systems (including stock markets, hospitals, neighbourhoods, etc) are controlled by processes of evolution. Evolution should be considered in the design and development of human habitat to avoid conflict with the nature of living systems. Systems which are not resilient (in the case of desirable resilience) cannot move to new levels of order. Therefore, resilience should be built into systems for them not only to return to their former state but also to evolve and be better.

2.5.3. Characteristics of Urban Resilience

An urban system should have certain characteristics which makes it adaptable and therefore resilient to risks and disaster. These are the characteristics which their existence would prove the system capable of absorbing, adapting and transforming in the case of perturbation to maintain the function of the system. Design for resilience requires building these characteristics into components which make up the system (Du Plessis, 2022). Literature has not, however, concluded on the characteristics of resilience, hence the different combinations of characteristics proposed by different authors.

Peres et al. (2017) describe the three main characteristics of urban resilience as: diversity, network modularity and redundancy (Peres et al., 2017). Du Plessis (2012a) gives the same sense by stating diversity, connectedness and tightness of feedback as the main characteristics of a resilient urban system. Ribeiro and Goncalves (2019) highlight eight attributes, which they also call “characteristics of urban resilience”: robustness, connectivity, independence, efficiency, resources, adaptation, innovation, inclusion, integration, as well as diversity and redundancy. Some characteristics seem to be overlapping, such as modularity and connectedness. It is further established that different contexts would require different interventions, which may explain the different combinations of characteristics proposed by different authors. It is of note as well that some characteristics are based on literature, some on practice, and some are specific about a certain dimension, and some are proposed for all dimensions. It is therefore important to be specific of the performance dimension being discussed and to clarify the targeted problems to solve. The characteristics set clear targets to foster resilience of urban systems and further presents how these systems should behave in times of perturbation (Wang et al., 2018). Table 2.8 below describes each characteristic along with sources where it is discussed.

Table 2.8. Main characteristics of urban resilience (Ribeiro & Goncalves, 2019)

	Characteristics	**Description**	**Author(s)**
1	Redundancy	Refers to the existence of alternative parts of the system which can act as a 'backup' in the case one component of the system fails.	Godschalk (2003), Allan and Bryant (2011), Wardekker et al. (2010), McLellan et al. (2012), Kim and Lim (2016) and Spaans and Waterhout (2017)
2	Diversity	Refers to the existence of a variety of components performing the same function to enable different responses to threats to protect the system.	Godschalk (2003) and Allan and Bryant (2011)
3	Efficiency	This refers to the ability of a system to resist disturbances to the system.	Godschalk (2003) and Kim and Lim (2016)
4	Robustness	This refers to the ability of a system to resist disturbances to the system.	Godschalk (2003), Wardekker et al. (2010), McLellan et al. (2012), Kim and Lim (2016) and Spaans and Waterhout (2017)
5	Connectivity	This refers to a connection in a network to enable it to be robust against failure and increase its resilience.	Godschalk (2003)
6	Adaptation	The ability of a system to absorb disturbance to sustain its function.	Godschalk (2003), Wardekker et al. (2010), Allan and Bryant (2011), Kim and Lim (2016) and Spaans and Waterhout (2017)

The work of several authors such as Nel et al. (2019), Du Plessis (2012a), Peres (2016), Davoudi et al. (2013), Holling and Gunderson (2002), Folke (2006), among others, have, however, not been highlighted in Table 2.6 even though they have made important contributions to the understanding of urban resilience. Connectivity appears to have been less discussed, based on the table, yet it has been extensively explored in Nel et al. (2019) and Holling and Gunderson (2002), which have not been referenced. There are also important characteristics in spatial resilience which have not been included, such as flexibility, yet this has much effect in controlling floods, according to Wang et al. (2018). Some characteristics may only be discussed in general Resilience Theory but could be very beneficial in addressing urban climate resilience. Further there is limited literature discussing these characteristics at building level, as the focus is mostly at neighbourhood and city scales, which may cause ignorance in planning individual buildings for climate resilience to complement the spatial city or neighbourhood planning.

The characteristics of resilience are not only expected in the physical dimension of a city as urban resilience is divided into five dimensions according to Ribeiro and Goncalves (2019): physical, natural, economic, institutional, and social. Physical resilience relates to resilience in infrastructure; natural resilience relates to the ecological and environmental resilience; economic has to do with the development of societies and economies; institutional resilience highlights governance and mitigation policies; and social resilience relates to resilience of communities and people in general (Ribeiro & Goncalves, 2019:4). This study, however, focuses on spatial resilience which exists in the physical dimension. However, the contribution of human systems is also a vital aspect to consider in the study of social-ecological systems.

The existence of the above characteristics can be evaluated in a neighbourhood to understand its general and even specific resilience such as climate change resilience (Stagrum et al., 2020). Climate-related disasters are categorised by the United Nations report on the Human Cost of Disasters, as “meteorological (e.g., storm, extreme temperature, and fog), climatological (e.g., drought, glacial lake outburst, wildfire), or hydrological (e.g., flood, landslide, and wave action)” (CRED, 2020). The sections below describe how some of the characteristics, aligning with socio-ecological resilience characteristics, can be developed in urban systems to strengthen the ability to respond adequately to changes caused by climate change. Based on the literature on urban resilience, the characteristics of connectivity, redundancy, modularity, and diversity are considered vital attributes which a system should have for resilience (Dastjerdi et al., 2021), and they are discussed below.

A. Diversity

Diversity refers to the variety of functions within a system as well as a variety of responses to those functions across various scales. Page (2010) gives three categories in which diversity can be viewed or studied within complex adaptive systems: diversity by type, diversity across types, and diversity of composition. Diversity by type is understood as variation and shows difference in the amount of an attribute. Diversity across types denotes differences between various types (types of plants, animals, etc.) and is also viewed as functional diversity. A system may respond differently for each functional group. In buildings this may refer to the mix of different typologies. Then diversity by composition is observed in different compositions of population groups. A resilient and healthy system has diversity (amongst other attributes), and "a lack of diversity limits options and reduces your capacity to respond to disturbances" (Walker & Salt, 2006).

Functional diversity in a city (physical dimension) is created by physical and structural components of the city such as infrastructure, buildings, and resources (Peres, et al., 2017). Infrastructure depicts the components that give a structure to the city and relates to movement networks such as roads, energy sources, water systems, and communication systems (Peres et al., 2017). In Longstaff et al. (2010) infrastructure has been described as "the substructure or underlying foundation or network used for providing goods and services; especially the basic installations and facilities on which the continuance and growth of a community, state, etc., depend...[and] include roads, water systems, communications facilities, sewers, sidewalks, cable, wiring, schools, power plants, and transportation and communication systems." Buildings on the other hand relate to the typologies, and resources represent environmental elements which support life in urban areas such as green open spaces, air quality and climate (Peres et al., 2017).

With regards to response diversity, several ecosystem services all executing a similar function of slowing down run-offs and lowering flood peaks, fall under response diversity (Nel, 2015). Holland (1998) gives a sense that if one service does not function for some reason, the system will respond by developing some adaptation in other services (agents) until the gap created is covered. The more diverse the agents are, the more complex the system becomes. However, Page (2010) warns that excessive diversity in a system may result in a collapse in resilience of that system.

Diversity in storm water management in New Orleans is illustrated in Ballsels et al. (2013) as rainwater absorption (tree canopy, vegetated roadside, swales, etc.), rainwater detention (pedestrian corridors and pocket parks, curb cuts, etc.) and rainwater temporary storage (parks with low areas, water basins, etc.). The absorption of rainwater reduces surface runoff and therefore reduces impacts to neighbourhoods. The retention and temporary storage of rainwater takes pressure off the pipelines, which prevents overflows and damage. The diversity in these water management processes increases the adaptability of the neighbourhood. In Skt. Kjeld Community, Copenhagen, flooding is managed by making more area for the storm water in the limited space it has by maximising the use of outdoor spaces through creating green spaces, green island squares, green courtyards, and public areas to create prevention of disasters (Wang et al., 2018).

Du Plessis (2012a) presents another way of using diversity to build resilience by increasing the range of responses to a certain function, such as energy provision, through what the author calls a 'modular approach' which establishes different responses at different scales. An example in energy provision is provided which would look at "on-site measures such as demand management and domestic solar water heating, neighbourhood solutions such as district heating and cooling or distributed generation capacity such as small-scale wind, hydro or solar, as well as bulk services from large power stations." The same concept can be applicable in water provision: onsite measures such as water harvesting, neighbourhood solutions such as community boreholes, as well as bulk services from dams servicing a whole city and its outskirts.

B. Redundancy

Redundancy refers to reserves or duplication or back up in a system that can always be used in case one sub-system fails, like in the case of a backup generator that can always kick in when electricity from the grid fails (Zoli & Healy, 2012). If something goes wrong in a part or function of the system, another one is available to take its place and perform the same function (Fleischhauer, 2008). Nel et al. (2018:254) have proposed questions that can assist in identifying the redundancy spatially in a complex adaptive system like a neighbourhood: "Will the system continue to function if a part of it collapses? Are there back-ups for different parts or functions of the system? Can a function of the system be performed by another part or agent(s)?"

Redundancy, just like diversity, is applicable spatially like in road networks to reduce vulnerability. In the case of road networks, more exit/entrance points, as well as increased links, contribute to redundancy and improves resilience as well as sustainability. Complex street networks with a range of connections are claimed to increase resilience capacity ensuring continued functioning of the city even when certain parts of the network are disconnected (Ahern, 2011; Nel et al., 2018). Discussions of redundancy by most authors are mostly based on road patterns or structure of a city. In the case of adaptation of a city to climate change, development of alternative routes can improve its adaptive capacity by limiting disturbance from blocked roads due to storms which normally cause trees to fall on roads, or flooding affecting bridges, or slippery/eroded roads due to rainfall events. In such cases, the transport network (movement) reorganises itself, thus building resilience.

At building level, redundancy can be translated into the functioning of building services. For instance, in the case of extreme temperatures, drought is expected to cause scarcity of drinking water. Redundancy in water systems means that in case of the failure of the public piped water supply, built-in water harvesting systems can take over to provide water to households for the function of water supply systems to be sustained. Meerow (2016) states that redundancy is applicable in both technical systems such as electricity infrastructure, and social networks. Buildings are normally powered by electricity from the grid, which can be affected by increased storm events. Redundancy in these systems would require decentralised renewable energy sources as backup systems that can take over in the case electricity from the grid fails. Du Plessis (2012a) mentions that when there is high redundancy created in the system, it may seem inefficient. However, several alternative methods for meeting energy needs would ensure that if energy from the grid (bulk supply) is not met for some reason, the alternative methods are available to at least run basic services.

Redundancy has the disadvantage of being expensive, especially to the neighbourhoods occupied by low-income groups, and it may be at odds with efficiency (Zhu & Ruth, 2013). Some literature claim that efficiency does not promote resilience (Friend & Moench, 2013) even though some scholars still list it amongst characteristics of resilience as in Table 2.6.

C. Modularity

Modularity refers to the development of flexible connections between subsystems in such a way that they can manage to operate independently and can also combine easily when required. This relates to the connectedness characteristic as well. Modularity in a system relates to the relationships between systems which build a certain pattern that affects future functioning of the whole system. Modular components in this case can easily accumulate or decouple in response to change allowing the system to localise shocks and maintain its functionality (Peres et al., 2017). Dhar and Khirfan (2017) state that modularity allows professionals and residents to retrofit or change only the elements which have been disturbed. Professionals employ modules as the basis of design or construction, such as modular housing units (Waguespack, 2010). Modularity reduces the impacts of climate change by making certain that the threat which affects system components of a neighbourhood do not spread to other parts of the system, allowing continued functioning of that system.

Its application could be in decentralisation of energy sources which are independent from the central system, which can ensure undisturbed energy supply during system failures (Dhar & Khirfan, 2017). Peres et al. (2017) demonstrate how modularity can be achieved in road patterns in gated communities such that an event affecting the main road link does not affect movement to the whole internal road systems.

D. Connectivity

Connectivity has been defined by Nel et al. (2018:922) as “a measure of the minimum number network components (nodes or edges) which must be removed from a connected network to disconnect that network.” The authors further state that it is a measure of resilience of the network, as a highly connected system is more robust against failure. Connectivity, as Cumming et al. (2005) state, enables bidirectional flow of information, assets, and capital. It is therefore a prerequisite for spatial resilience and protecting the urban system against unexpected failure after perturbation (Ahern, 2011). Nel et al. (2018) claim that a system with low levels of connectivity can have several points of failure, giving an example that if circulation is forced through single points of failure, traffic jams can be experienced causing failure in circulation networks. Multiplicity of connections further builds the system’s capacity to adapt and evolve through creating interaction opportunities and enabling the system to reorganise itself should there be a need. However, some authors claim that over-interconnected systems can aggravate more effects and further create new issues (Olazabal et al., 2018; Pickett et al., 2014), and it leads to inefficiency according to Feliciotti et al. (2016).

The discussion of connectivity in spatial resilience is mostly limited to city movement networks, however this concept can also be applicable to drainage systems. Storm drains in cities, especially within informal settlements, are blocked by solid waste resulting in failure of the drainage system. A highly connected drainage system may be less flooded due to the alternative channels which can relieve the system.

The discussed characteristics of resilience systems enable them to persist, transition, or transform to sustain the function of the system.

2.5.4 Determining the resilience of a system

With reference to the Resilience Alliance (2010:35), there are three steps that need to be followed to determine the general resilience of a system.

a. "Develop a working list of system components or areas where low diversity (or other attributes) or trends in diversity (or other attributes) may be a trend."
b. "In which parts of the system is there little or no diversity (or other attributes) which might render the system vulnerable to a loss of function?"
c. "Are there any trends that reflect declines in diversity (or other attributes)?"

The study argues that to assess the resilience of the focal system, it requires to break down the system to its parts (sub-systems) that make the system whole, then assess the resilience of the parts. This means some parts may be found to be resilient, but some may be vulnerable to disturbances. The parts which are resilient will require to be maintained and resilience will be built into the subsystems which are vulnerable. Physical and structural components that make up a city have been determined from a zoning perspective using categories such as retail, industrial and residential (Ferreira & Du Plessis, 2013). However, Peres (2016:165) has argued that this classification gives no idea of the spatial character or flow through the city and does not show the full potential that the city holds to evolve in a resilient manner. The author argues that while in a natural system the functional groups which give a structure to the system are producers, consumers, and decomposers; in an urban environment the functional groups claimed to make a city function as a city are infrastructure, buildings, and resources as shown in Figure 2.4.

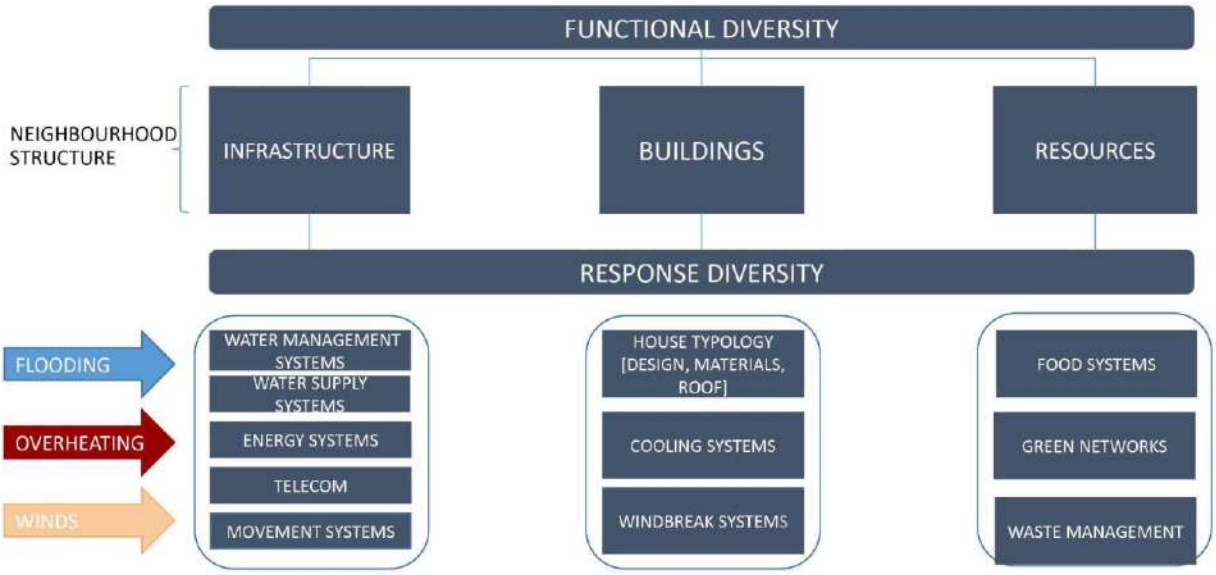


Figure 2.4. Functional diversity in a hypothetical urban habitat (Peres, 2016)

'Infrastructure' refers to services and utilities such as movement networks, energy systems, and water systems. 'Buildings' on the other hand relate to typologies. 'Resources' refer to environmental qualities which maintain life in the city. This study adopts this classification (as it is supported by findings in chapter 4) to divide the system (city) into components in which their resilience should be assessed. The components shown in Figure 2.4 are those expected to respond to the impacts of climate change such as flooding, overheating and changes in wind patterns. For example, energy systems in a city are expected to function even when there are strong destructive storms. This can be done by building redundancy into the energy systems such that when one system fails, another one takes over as a backup system.

2.5.5. Urban Climate Change Resilience

The above sections discussed general resilience, which focuses on resilience to all kinds of shocks, including completely unexpected ones. It does not specify the component of a system which is at risk of crossing a threshold or define the shock which the system is at risk to endure (Folke et al., 2010). It is undeniable that a system can be more at risk to a particular known shock, therefore, practically resilience is normally applied to problems relating to specific aspects of a system which may arise from a particular source of shocks or disturbances, and this is termed as “specific resilience” (Folke et al., 2010). Carpenter et al. (2001) state that specific resilience rises in response to the question “resilience of what to what?”. In the case of this study, the concern is on the resilience of vulnerable components of the urban systems to climate change impacts.

Resilience is a very critical concept in the debate of climate change and adaptation (Satterthwaite et al., 2020). The IPCC (2014) report proposes creating a resilient pathway as a way to respond to climate change risks which are concentrated in urban areas (Kim & Lim, 2016). Climate change resilience is a vital concept in cities because these areas consist of interdependent closely linked sectors and activities as in the case of an organism (Zhao et al., 2013). Rapid urbanisation increases the demand for housing, basic services, and resilience to climate-change impacts (Satterthwaite et al., 2020). Population density, combined with economic assets and city services, make urban areas highly vulnerable (Rafael et al., 2015). Cities are therefore claimed to be more vulnerable to climate change when compared to rural areas.

Vulnerability refers to the level to which a system is defenceless to adverse effects of stressors (Fussel, 2007). Romero-Lankao & Qin (2011) argue that vulnerability should be defined based on three concepts: exposure, sensitivity, and capacity to adapt. These are properties of a system which are dependent on the interaction between the characteristics of the system and on the attributes of the surrounding environment, namely climate stimulus. Exposure refers to the level, duration, and/or extent to which the system is in contact with, or subject to, the perturbation (Adger, 2006). According to the IPCC (2001), sensitivity is “the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli”. In general, adaptive capacity is defined as “the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences” (IPCC, 2001). Based on these three concepts, Rafael et al. (2015:385) define the concept ‘vulnerability’ as “a function of the exposure and sensitivity of that system to a stressed condition and the ability or capacity of the system to cope, adapt or recover from the effects of those conditions”.

Informal settlements are considered the most vulnerable areas to climate change in the city, as evidenced by the recurrent climate related shocks and stressors (Muchiri & Opiyo, 2022, Satterthwaite et al., 2020). This is because these areas are located in areas which are more susceptible to climate change impacts, making their exposure to such impacts very high. A majority of the global urban population lives in these areas with poor houses or shacks which are less able to withstand high winds and flooding (Douglas, et al., 2008). Further, due to the materials informal settlement dwellers use for their houses, these areas are highly vulnerable. These informal settlements therefore require urgent attention to create resilience to climate change due to their vulnerability to climate change effects such as flooding, landslides, heavy storms, and extreme heat, among other impacts (Revi et al., 2014). As these areas are mostly occupied by the poor, the lack of financial power of the residents results in a low adaptive capacity. In these areas, residents cannot afford to build stronger structures when compared to the formal part of the city. It is claimed that in these areas, city authorities have not developed ‘risk-reducing infrastructure and services relevant to resilience’ (Revi et al., 2014).

Building resilience may be embedded in the upgrading programs, many of which are driven by communities and supported by local governments (Satterthwaite et al., 2020). Some of these programs aim to formalise these areas, therefore tipping a threshold to improve living conditions. This is acceptable in evolutionary resilience. However, the cost of formalisation needs to be reduced to avoid displacement of the residents living in informal settlements. Since it has been established that most people living in these areas are the urban poor (Bredenoord, 2016), affordability and constructability should be prioritised. Building resilience into self-help housing (house construction managed by the residents) and service installations by the local authorities might prove to be the most affordable method. ‘Self-help’ developers will control the incremental construction to suit their affordability, however they need a guide on how to build resilient self-help houses (Ndlangamandla & Combrink, 2018). On the other hand, local authorities that may be funded by the government, also require a guide on how to build infrastructure and resources that will be resilient to the impacts of climate change.

Considering that resilience thinking provides a framework for dealing with adaptive change and behaviour of living systems to maintain essential functions (Davoudi et al, 2013 and Du Plessis, 2012a), such functions in informal settlements should be defined. In general, they include provision of affordable housing and provision of access to essential services at low cost. The continued existence of these settlements is vital also, since it is where one out of three people live (Dovey & King, 2011). The goal of building resilience in informal settlements, therefore, should be improvement of living conditions such as improving environmental quality, reduction of poverty, provision of access to essential services and housing at low cost.

Resilience assessment of settlements is critical in order to identify where interventions and strategies to build or enhance resilience are necessary. The following section reviews several resilience assessments and reflects on the nature of a resilience assessment tool that can be used in assessing the climate resilience of informal settlements.

2.6. Review of Urban Resilience Assessment Frameworks

There are several international resilience assessment frameworks aimed at understanding and evaluating the resilience of cities (Patel & Nosal, 2016). The following subsections review five international resilience assessment frameworks developed for cities. These are: the City Resilience Index, City Resilience Profiling Tool, Disaster Resilience Scorecard for Cities, City Resilience Action Planning Tool, and Resilience Assessment Framework by Resilience Alliance.

2.6.1. City Resilience Index (Rockefeller Foundation & Arup, 2014)

The City Resilience Framework was developed over three years by Arup, with the support of the Rockefeller Foundation, to assess the resilience of cities, identify vulnerable areas or areas of improvement, and identify possible actions to improve the city's resilience (Rockefeller Foundation & Arup, 2014). It is based on extensive research contributions and pilot schemes conducted in 28 diverse cities across the world. The approach is to identify drivers which contribute to resilience of cities and use them to assess the level of resilience. This tool, adopted by the 100 Resilient Cities to guide the development of City Resilience Strategies across the world, helps cities to understand and evaluate their capacity to endure, adapt, and transform to keep the cities functional (Arup, 2017). The CRI is based on four dimensions and 12 goals which each city should aim to meet to achieve resilience, and 52 indicators which are critical to evaluate the resilience of a city (Arup, 2017) as shown in Figure 2.5 below.

The four dimensions which make up the CRI are health and wellbeing, economy and society, infrastructure and environment, and leadership and strategy. The drivers are summarised below as presented by Rockefeller Foundation and Arup (2014).

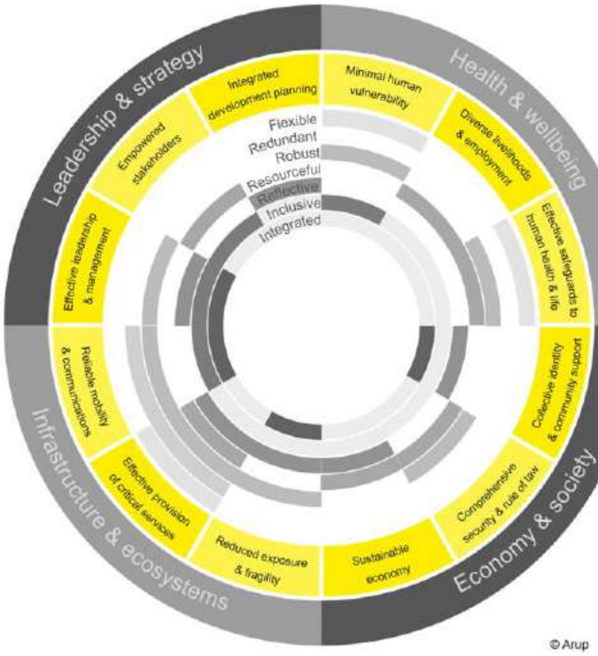


Figure 2.5. City Resilience Index (Arup, 2017)

- *Health and wellbeing*

This dimension refers to the health and wellbeing of the population living and working in the city. There are three goals under this dimension which include: a) meeting basic needs through provision of essential resources to meet a person's physiological needs; b) support livelihoods and employment to enable people to meet their basic needs; c) and ensuring public health services.

- *Economy and Society*

This refers to the social and financial systems which ensure that the urban population live peacefully and participate in unity. The three goals under this dimension include: a) the promotion of cohesive societies and engagement of communities to improve a community; b) ensure social stability, security, and justice for law enforcement, prevent crime, and manage emergency; c) foster economic prosperity on a wider scale, which include the ability to attract business investments, foster diverse economic profile, and proper management of city finances.

- *Infrastructure and environment*

This refers to the way in which man-made and natural infrastructure provide critical services and provide security to the urban population. The drivers under this dimension include enhancing and providing protective natural and man-made assets through environmental stewardship, appropriate infrastructure, effective land use planning, and enforcement of regulations; ensure continuity of critical services through diversity of provision, redundancy and proper maintenance of ecosystems and infrastructure; and providing reliable communication and mobility through diverse and affordable multi modal transport networks and systems, ICT, and contingency planning.

- *Leadership and strategy*

This dimension encompasses effective leadership, empowered stakeholders and integrated planning. The three goals under this dimension include promoting leadership and effective management relating to government, business, and civil society; empowerment of broad range of stakeholders to ensure citizens take the proper actions; and fostering long term and integrated planning with building codes creating safety and removing negative impacts.

The CRI addresses resilience generally at city level and focuses more on overall capacity of a city to continue functioning. It does address the physical component of a city in the infrastructure and environment dimension which touches on urban systems and services (place). This gives a sense that a city with poor quality infrastructure contributes to poor resilience (Rockefeller Foundation & Arup, 2014). This dimension, however, does not allow specific identification of the spatial and material components of the city which contribute to spatial resilience to guide planning practitioners on how to re-structure the physical fabric of the city to keep it functional. The goals highlighted focus on performance describing the outcomes of actions but do not describe the actions which need to be taken to achieve that desired outcome. For instance, the target is ‘appropriate infrastructure’, however the design of appropriate infrastructure is not defined. The tool does acknowledge that appropriate function relies on appropriate design and construction. The tool can form a base for more detailed frameworks to guide developers to design or retrofit infrastructure and building or improve ecosystems to increase resilience of the different dimensions of the city.

2.6.2. City Resilience Profiling Tool (UN-Habitat, 2017)

The City Resilience Profiling Tool (CRPT) provides a framework to assess resilience in urban areas through outlining the context of the city including stakeholders, shocks and stresses, and further identifies gaps and opportunities regarding the city’s structure and functionality to inform decision-making tailored for the study area (UN Habitat, 2017). This tool provides a framework for data collection and provides a holistic approach to building resilience to shocks and stresses in urban areas.

The implementation of the CRPT follows a process (Figure 2.6) with five phases, starting with initiation and training, then data collection and diagnosis, analysis, action for resilience and finally taking it further. The initiation and training phase encompasses the formal engagement of UN-Habitat by the city's authorities, presentation of the CRPT and continual training and support through regular conference calls.

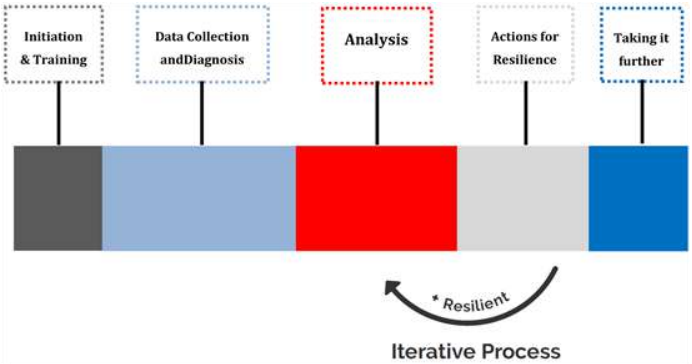


Figure 2.6. City Resilience Profiling Tool implementation process

The next phase is data collection through a series of questions answered by the local government with assistance from a member of the UN-Habitat team, and the data is input into UN-Habitat's software to create a resilience profile for that study area (city). Data collection is divided into four SETs as overviewed below.

- *SET 1 – City ID*

This SET provides the overall picture of the city's development through its history and spatial context. The contextual information such as the historical context, spatial context, local government and public administration, population and demographics, economy and livelihood and hazards and challenges, is used for diagnosis and action. This information about the realities of the city is collected through in-depth inquiries in the data collection.

- *SET 2 – Local governments and stakeholders*

This SET provides a framework for a holistic analysis at several levels to provide an analysis of the functionality of the urban system with the focus on governance. It looks at the status of city governance and how improvable it is through analysis of stakeholders such as public institutions, private sector, civil society, academia, and international organizations. SET 2 considers the functions of governance in ensuring resilience in the city to identify areas of improvement. Key analytical functions of SET 2 are therefore looking at the role and place of different public administrations, and stakeholders' mapping (UN-Habitat, 2017).

- SET 3 – Shocks, stresses, and challenges

This SET evaluates the exposure of the city to stresses, shocks, and future challenges, and the existence and performance of systems placed to decrease possible impacts of identified threats. This SET identifies internal stresses and shocks originating from the system, external stresses and shocks, and complex stresses which arise from both internal and external stresses/shocks. Furthermore, risk/vulnerability reduction measures are identified.

- *SET 4 – Urban elements*

SET 4 considers all elements which make up the urban area such as the built environment, supply chain and logistics, basic infrastructure, mobility, municipal services, social inclusion and protection, and ecology. This SET, like the other three SETs, provides a framework for an in-depth analysis of the urban system. Data collected include data about performance and characteristics of the urban system's elements, with specific questions dedicated to the assessment of each element's performance. This exercise provides understanding of the urban system's strengths and weaknesses as well as evidence on which to base future interventions.

The built environment aspect analyses the city in four layers: urban form looking at growth patterns of the city, land tenure and housing focusing on issues of right to proper shelter, and physical built quality of assets which provide essential services to the urban population. This addresses important issues of informality. The supply chain and logistics focuses on how critical resources (non-human) are accessed, distributed, and managed in the city. It assesses the availability of essential resources in times of crisis looking at water resources, energy resources, and food supply and logistics. The basic infrastructure are the vital resources to empower people and communities to provide for their economic, social, environmental, and cultural wellbeing (UN-Habitat, 2017). This tool assesses the performance of these systems such as energy, water, solid waste and telecommunications. Mobility refers to the ability of the city to move people within, from, and to the city. The tool therefore assesses the city's transport capacity for resilience evaluating diversity, redundancy, and robustness of different modes of transport. The focus of this element is on urban mobility and inter-regional mobility. Municipal services are considered an essential component of the city which should be provided by governments to city residents. The tool analyses the services delivered by the municipality of the assessed city and identifies those that require attention to improve resilience. The municipal public services recognised by the tool include cemeteries and crematoriums, civil registration, criminal justice and law enforcement, cultural heritage and cultural activities, emergency and rescue services, food inspection and monitoring institutions, communicable diseases surveillance and response system, municipal taxes and fines, and public lighting. The Social inclusion and protection element allows for evaluation of resident's access to their basic developmental rights such as basic social protection and social services such as education, health, food, and social care. The Economy urban element assesses the ability of the economy to enable the system to cope with stresses and shocks. It evaluates the economic stability and diversity, economic context, and market efficiency. Lastly, the Ecology urban element is considered with the understanding that human settlements rely on and interact with ecosystems for provision of food, fresh water and clean air, and spaces of worship, among other services. The CRPT tool provides a framework to analyse the city's environmental resilience in relation to human health. It studies ecosystem services, ecological footprint, biodiversity and green areas, and environmental quality.

The next phase following data collection is 'actions for resilience' which provides a roadmap for authorities to build resilience based on the collected evidence about stresses, shocks, and challenges. It considers five dimensions: national urban planning, rules and regulations, planning and design, financing urbanization, and local implementation. Lastly, upon defining the Actions for Resilience, the local government presents the actions to stakeholders and roles and responsibilities are assigned.

2.6.3. Disaster Resilience Scorecard for Cities (UNDRR, 2017)

The Disaster Resilience Scorecard for Cities was developed by the United Nations Office for Disaster Risk Reduction (UNDRR) with the support of USAID, the European Commission, IBM and AECOM. The scorecard is used to understand the disaster risks, mitigate risks, and respond to disasters to minimise damage on livelihoods, infrastructure, property, environment and economy (UNDRR, 2017). It is structured around UNDRR's "Ten Essentials for Making Cities Resilient" (Figure 2.7) developed as part of the Hyogo Framework for Action and later to support implementation of the Sendai Framework for Disaster Risk Reduction: 2015 – 2030, and enable the development of resilience action plans. This covers several issues which cities should address to be resilient to disasters.

The first 3 essentials address governance and financial capacity, then essentials 4 to 8 address several dimensions of planning and disaster preparation, and essentials 9-10 cover the disaster response and post-event recovery. The Scorecard can be used to score at two levels, a preliminary level and detailed assessment. The Preliminary level, which is also level 1, responds to key Sendai Framework targets and indicators, and can be used in 1-to-2-day multi-stakeholder workshops. At this level, there are 47 questions or indicators with a score of 0 – 3.

The detailed assessment, also called 'level 2', is a multi-stakeholder exercise which takes 1 to 4 months, forming a basis for a detailed resilience action plan. This level includes 117 indicator criteria with a score of 0-5.

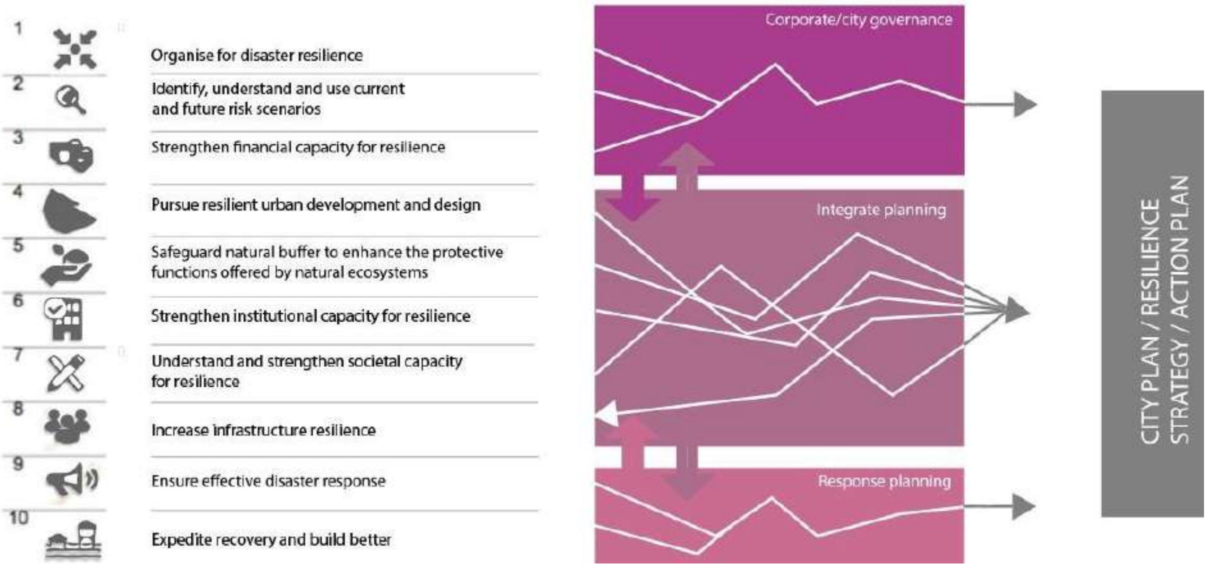


Figure 2.7. The Ten Essentials for Making Cities Resilient (UNDRR, 2017)

The essentials which relate to the study are essential 4 to 8. Essential 4 addresses the following issues: land use zoning, new urban development, building codes and standards, and application of zoning building codes and standards. Essential 5 is about safeguarding natural buffers to enhance the protective functions offered by natural ecosystems and addresses existing natural environment and ecosystem health, integration of green and blue infrastructure into city policy and projects, and transboundary environmental issues. Essential 6 (strengthen institutional capacity for resilience) focuses on rate skills and experience, public education and awareness, data capture, publication and sharing, training delivery, languages, and learning from others. Essential 7 deals with understanding and strengthening of societal capacity for resilience, scores community or 'grass roots' organizations, social networks, private sector/employees, and citizen engagement techniques. Essential 8 deals with increasing infrastructure resilience and evaluates protective infrastructure, water sanitation, energy/electricity, energy-gas, transportation, communication, healthcare, education, prisons, administrative operations, and computer systems and data.

2.6.4. City Resilience Action Planning Tool (UN-Habitat, 2020)

The City Resilience Action Planning Tool (CityRAP) developed by United Nations Human Settlements Programme (UN-Habitat) and the Technical Centre for Disaster Risk Management, Sustainability and Urban Resilience (DiMSUR) aims to "enable local governments of small to intermediate sized cities, or neighbourhoods/districts of bigger cities or metropolitan areas, to plan and undertake practical actions to strengthen the resilience of their cities" (UN-Habitat, 2020:6). This tool targets local governments of cities with a maximum of 250,000 people in the developing world with limited experience in addressing risks and planning for resilience. The CityRAP aims to strengthen the capacity of city managers and technicians to build resilience in their cities with minimum involvement of outside experts.

This tool is implemented in four phases for an estimated period of three months. The four phases are understanding urban resilience as phase 1, data collection and organization as phase 2, data analysis and prioritization is in phase 3, and phase 4 is development of the city resilience framework for action (RFA) as shown in Figure 2.8 below.

Figure 2.8. The CityRAP Tool (UN-Habitat, 2020)

Phase 1 (understanding urban resilience) is all about training of the municipal and local stakeholders about urban risks and resilience concepts, by external trainers. The last day of the five-day course focuses on training a small group that will lead the process at city level, referred in this tool as 'Municipal Focal Points'. A risk map of the city is developed through participation. Phase 2, which is about data collection and organization, has a focus on collection of data about the status of the city's resilience conducted by municipal departments using a questionnaire, and priorities of communities for strengthening resilience of their neighbourhoods. Activities under this phase include municipal self-assessment, participatory planning at neighbourhood level, and data compilation and organization.

Phase 3 is about data analysis and discussion of data through focus group discussions. The priority issues are selected through five focus group discussions. A maximum of six priority issues which contribute to building resilience are selected and a 10-year vision of the resilient city is developed. Activities in this phase include preparing the focus group discussions, focus group discussions, prioritisation workshop, and training of the municipality focal points for activity 1 of phase 4. Lastly, phase 4 is concerned about development of the city resilience framework for action (RFA) based on the results of the prioritization workshop. The City RFA is the final output of the CityRAP tool and provides a framework for building a city's resilience. Activities under this last phase include a baseline assessment of the identified priority issues, definition of priority actions and RFA formulation workshop, and preparation of the first consolidated draft of the city RFA.

2.6.5. Resilience Assessment Framework by Resilience Alliance (2010)

Another identified resilience assessment framework capable of evaluating the resilience of social-ecological systems is the one developed by Resilience Alliance (Figure 2.9) over a decade ago. This assessment framework can provide insights into how strategies for addressing change can be developed. It is based on the concept of social-ecological systems (SES) in which human and ecological systems are considered one integrated system.

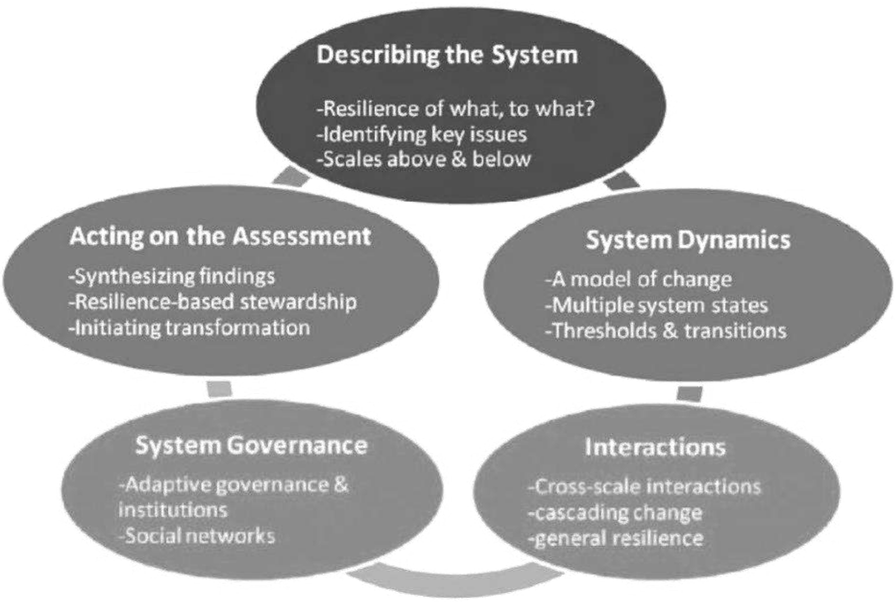


Figure 2.9. Resilience Assessment Framework (Resilience Alliance, 2010)

The assessment framework has five main stages with the first stage describing the system, the second stage understanding the system dynamics, the third stage probing system interactions, then evaluating governance for the fourth stage, and finally acting on the assessment.

According to the Resilience Alliance, the process is iterative and reflexive at each phase and needs going back to previous steps and revising where required.

- *Step 1: Describing the system*

Describing the system involves defining the social-ecological boundaries of the system which will be assessed. The boundaries can be spatial and temporal, and they comprise what is referred to as a ‘focal system’ (Resilience Alliance, 2010). The idea is that any system is influenced by factors which lie within or outside its boundaries therefore cross-scale system interactions should also be considered in the resilience assessment. The boundaries of the focal system should be adjustable because what is critical in the system may change as the understanding of the system and issues improves (Resilience Alliance, 2010). This is the first step in assessing a focal system by the Resilience Alliance involving identification of the main issues of concern; identification of key components of the social-ecological system which relate to the main issue of concern; identification of the disturbance which the focal system should be resilient to; and identification of change drivers affecting the system at different scales and how they have changed the focal system over time.

- *Step 2: System dynamics*

The second step in the assessment is determining the dynamics of the system with the understanding that social-ecological systems experience both gradual and rapid changes (Resilience Alliance, 2010). Most systems are claimed to be dynamic and change over time, in most cases following four phases: growth, maintenance, collapse, and reorganisation as discussed in previous sections. These are phases of the adaptive cycle which provides an understanding of the dynamics of a system over time. This step also involves describing the current state and historical and potential future states of the system. It further involves understanding how a system moves between multiple states and learning how to establish transitions to achieve required outcomes. This allows for proper interventions in the system in managing it.

- *Step 3: Interactions*

The third step in the assessment aims to determine the interactions across scales with the understanding that a social-ecological system interacts with and is influenced by larger-scale systems in which it is embedded, as well as the smaller-scale systems (subsystems) of which it is composed (Resilience Alliance, 2010). It determines how the larger scale systems either stimulate change or constrain the focal system. Further it can be determined if there are opportunities for leveraging cross-scale interactions to achieve desirable outcomes at the focal scale. This looks at the panarchy of the system. Thresholds of potential concern can also be identified at this stage. This is also the stage where general and specified resilience of the system is assessed through identification of the attributes of general resilience. This can be determined through identifying components or areas where low diversity (or other attributes such as openness, tightness of feedback, modularity, etc.) or trends in diversity (or other attributes) may be of concern. Further parts of the system where there is little or no diversity (or other attributes) which might render the system vulnerable to a loss of function are identified (Resilience Alliance, 2010). This helps in identifying areas that need to be enhanced.

- *Step 4: System governance*

The fourth step is understanding governance to understand social-ecological system interactions in the focal system. Governance systems are described by the Resilience Alliance (2010:36) as "dynamic entities that include a variety of institutions and stakeholders and involve multiple sectors and scales." How these systems interact determines how people make decisions, share power and exercise responsibility. In this step therefore, formal and informal institutions which have a bearing on decision making within the focal system are determined, as well as how they enhance or constrain flexibility to address issues as they arise in the system. Further, social networks are mapped among stakeholders and linkages between the stakeholders operating at different hierarchical or geographical scales are considered, as well as how the linkages might benefit collaborative governance processes.

- *Step 5: Acting on the assessment*

The last stage concerns acting on the assessment by synthesising the assessment findings. The information gathered in the assessment through the stages above is employed as a basis for developing two conceptual diagrams which help in synthesising the assessment findings. The synthesis is claimed to be unique for each system and yield unique sets of follow-up questions, proposed interventions and strategies for conserving or building resilience. The overall goal is to sustain the capacity of the SES to provide benefits to society.

The identified frameworks present different approaches and dimensions of assessment where the tools aim to strengthen resilience of cities, and the developers of the frameworks further present their implementation process. Table 2.9 compares the frameworks by presenting their dimensions of assessment and how they manage risks. All the frameworks except for the resilience assessment framework by Resilience Alliance, have defined dimensions of resilience assessment. These dimensions presented in Table 2.9 also have sub-dimensions. The dimensions of resilience however seem to depend on the themes under assessment. Summers et al. (2017) have identified the five most common dimensions of resilience based on literature: environmental, social, economic, built environment, and infrastructure. The dimensions presented in the frameworks can also be aligned with this categorisation and with the United Nations's sustainable development goals (UN, 2015) as the aim is to keep the cities functional to meet sustainable goals.

The commonalities of the frameworks include their availability to all cities for adoption, they support the development of cities towards meeting sustainable development goals, and they consider a multi-sectoral approach. As much as they are all implemented differently, they all involve understanding of the vulnerability of the city and acting to improve the resilience of the cities. The structures of the frameworks differ as they follow different formats such as index, scorecard, model, or toolkit.

Table 2.9. Urban Resilience Frameworks and their dimensions of assessment

Framework	**Reference**	**Risk Management**	**Dimensions of Assessment**
City Resilience Index	Rockefeller Foundation & Arup (2014)	Reduce exposure	Health and Wellbeing Economy and society Infrastructure and environment Leadership and strategy
City Resilience Profiling tool	UN-Habitat (2017)	Identify shock and stresses	City ID Local governments and stakeholders Shocks, stresses and challenges Urban elements
Disaster Risk Scorecard for Cities	UNDRR (2017)	Identify hazards and exposure	Governance and financial capacity Planning and disaster preparations Disaster response and recovery
City Resilience Action Planning Tool	UN-habitat (2020)	Urban disaster risk management	Urban governance Urban planning and environment Resilient infrastructure and basic services Urban economy and society Urban disaster risk management
Resilience Assessment Framework	Resilience Alliance (2010)	Addresses change	Dimensions determined through a defined process (system description process)

The resilience assessment developed by the Resilience Alliance (2010) is a flexible framework which does not limit the user to specific dimensions of assessment but provides a process for deep understanding of the system of concern and provide relevant solutions to the identified disturbances. Different dimensions of assessment are developed from different assessments. Its flexibility makes it useful to any context, especially the areas which are normally ignored in city development such as informal settlements (UN-Habitat, 2018). Actions taken to improve the formal part and informal part of the city may be different. This study adopts this framework and considers the base laid by all the other international frameworks. The frameworks further provide understanding of the level of preparedness of the urban systems, recovery time, and level of adaptation to future climate related disturbances. The frameworks use different methods to achieve this. Methods and tools used in urban resilience assessments are listed in Tong (2021) as conceptual/theoretical framework, mapping, interviews, indicators or indexes, numerical method, and survey (Table 2.10). However, it is vital to integrate the methods/tools to be able to capture visualized data related to geographic information and assess the performance of the system at the same time.

Table 2.10. Applied methods in urban resilience assessment (Tong, 2021)

Method/Instrument	Applicability	Resilience metric	Limitation
Conceptual/theoretical framework	Is used to understand the hazards, threats, and trends, define urban resilience, identify needs and priorities for building resilience into urban ecosystems, specify methods to measure and quantify urban resilience [Collier et al., 2014, Bruneau et al., 2003].	Theoretical approach to understand and analyse resilience.	Rely on the experience and knowledge of the individual.
Mapping	Is used to collect, analyse, visualize data related to geographic information.	Resilience is quantified as the quality of a single system's components and their relationship.	Require updated data and skills of mapping software.
Delphi method	Is used to collect subjective information from experts.	Theoretical approach to select, define, weigh variables as related to resilience.	
Interviews	Is used to collect data extensively and intensively, facilitate understanding, obtain evidence, and exchange knowledge and experience.	Qualitative approach to collect, analyse, and interpret resilience.	Lack of standardization, representativeness, time-consuming, costly.
Indicators or Index	Are used to record and assess the performance, achievement, goal, change, characteristic, etc.	Diverse metrics are used to compute the characteristics and dimensions of resilience.	Require a rigorous and rational way for interpretation and analysis.

Method/Instrument	Applicability	Resilience metric	Limitation
Numerical method	To solve mathematical problems that are formulated in urban resilience assessment, such as optimization, simulation, and fuzz [McClymont et al., 2019].	Resilience is computed as the quality, performance, function of network systems.	Rely on the integrity and consistency of urban data.
Surveys	To collect a broad range of data from a target population, including their attitudes, values, feelings, behaviour, etc.	Resilience is quantified based on the behaviour and the life quality level of its inhabitants [Bozza et al.,2017].	Rigidity and potential bias.

2.7. Conclusion

There is enough evidence from literature that social-ecological systems are constantly changing due to external and internal disturbances, including from natural disasters such as those caused by climate change. Climate change is considered as one of the major and urgent challenges faced by humanity in the 21st century (Roggema, 2009). Changes in climate are blamed on the increase of GHG in the atmosphere emitted through anthropogenic activities. These gases capture more thermal energy which causes the global average temperatures to increase (Stagrum et al., 2020). This has resulted in climate change effects such as flooding, overheating, storms, and drought, which have affected millions of people around the world.

These climatic changes are causing risks mostly to the vulnerable living in low and middle-income countries with some linked to decline in food security, migration, and poverty (IPCC, 2014). The most vulnerable areas to climate change impacts are claimed to be informal settlements since they are not well serviced and they lack risk-reducing infrastructure (paved roads, storm and surface drainage, piped water, etc.) and services addressing resilience (including health care, emergency services and rules of law) (Revi et al., 2014). According to these authors, these settlements are not well prepared for climate change, making them exposed to floods, heavy storms, and heat waves. While this is an urgent issue, there is limited literature focusing on developing understanding on how the physical structure of informal settlements can be prepared for the impacts of climate change. Resilience thinking is believed to bring a framework for understanding and dealing with change in such cases, hence its exploration in this study as a lens through which change is understood.

The use of the term ‘resilience’ in different disciplines has, however, brought confusion in its interpretation and uses, and its practical application in the built environment is still questionable, according to some authors such as Alexander (2013). Resilience has different meanings in different contexts, however there is a commonality in all that this is a useful term in dealing with change in complex systems.

There are three common approaches dealing with the resilience concept in socio-ecological systems which seem to be dominating literature, namely: engineering resilience, ecological resilience, and evolutionary resilience (Davoudi et al., 2012). Engineering and ecological resilience have dominated literature for over two decades and claimed to be foundational (Peres, 2016), and evolutionary resilience being recent, with its exploration in literature growing rapidly. Engineering resilience focuses on maintaining stability closer to an equilibrium state after a disturbance and it attempts to return systems back to their original state (the state before the disturbance occurred). Ecological resilience, on the other hand, accepts the existence of multiple equilibria in systems, and ability of a system to shift to an alternative stability domain (Davoudi et al., 2012). The discussion of both engineering and ecological resilience circulates around equilibrium. The consideration that aspects of a system (social-ecological system) may change, adapt and transform post disturbance by collapsing or regenerating to a state which can increase the capacity of a system to survive (Walker & Salt, 2012), brought a new approach which has been termed as evolutionary resilience. All other definitions of resilience can be associated with any of the three concepts. These approaches have created a base to the study of resilience thinking, and the current understanding of resilience seems to integrate all three of these concepts.

The study, considering the transformative nature of resilience, and the dynamics of living systems along with dynamics of change within these systems, sits in the evolutionary resilience camp. Change in this case is addressed mainly through absorption (engineering resilience), adaptation (ecological resilience), and transformation (evolutionary resilience). The key question therefore is on how urban systems (informal settlements in this context) can be planned and designed to become more adaptive to change (more especially change with uncertainty like climate change) and further have the ability to meet sustainability goals through absorption of shocks, adaptation to change, and transformation, if required, to keep systems functioning.

Resilience theory has provided attributes mainly rooted in ecology, which should be translated to urban systems to understand complex socio-ecological systems (Folke, 2006) and further address change in urban systems. These attributes include multiple stability regimes, episodic change (adaptive cycle), multiple distinctive scales with cross-scale interactions (panarchy) and resilience itself. Walker and Salt (2006) have termed these as system characteristics of the resilience framework. Cities and their subsystems (such as affordable settlements) viewed as social-ecological systems are supposed to have these attributes.

Resilience in urban areas is concerned with how development and progress can be sustained in cities in the face of disturbances (Kim & Lim, 2016). Developing such an ability requires a new approach in urban planning and management as climate change impacts intensify, to eliminate the threat to the prosperity of cities. The complex systems within a city (which is a complex system itself) make it difficult to address future challenges that may be caused by climate change using current planning methods.

The understanding of cities as social-ecological systems suggests that the properties to consider in the discussion of sustainability of cities should include the properties which constitute resilience thinking: resilience, adaptability, transformability, connectivity, and diversity (Du Plessis, 2011). Social-ecological systems are defined as 'complex adaptive systems, where agents interact in unplanned and unpredictable ways' (Folke et al., 2016). They have multiple interconnected elements which through their interaction (Du Plessis, 2011) give birth to patterns at a broader scale, which again influence the interactions of the agents and the system as a whole, causing the properties of complex adaptive systems to change and form properties of the whole (Folke et al., 2016).

The understanding of cities as complex adaptive systems brings attention to their evolutionary nature which should be considered in addressing change. For instance, an awareness that a city consists of urban components which are related, and which interact and produce ripple changes across different scales of the whole urban system (Du Plessis, 2009) allows an understanding that managing a single component of the urban system (such as affordable settlements) will further influence other components (such as adjacent commercial centres) and the system as a whole which will further have new properties.

There are several requirements discussed in literature contributing to the resilience of a system, which create a framework for developing urban resilience. These attributes are required in all systems intending to build capacity in urban systems to adapt to changes. The most common attributes considered in this study include diversity, network modularity, redundancy and connectivity (Du Plessis, 2012; Meerow et al., 2016; Peres et al., 2017; Ribeiro & Goncalves, 2019; Wang et al., 2018). Further, it is believed that a social-ecological system with these attributes can be considered sustainable, as resilience is key in determining sustainability of socio-ecological systems (Holling & Gunderson, 2002; Brand & Jax, 2007).

This chapter reviewed several resilience assessment frameworks (City Resilience Index, City Resilience Profiling Tool, Disaster Scorecard for Cities, City Resilience Action Planning Tool, and Resilience Assessment Framework) which use different methods and tools such as conceptual framework, mapping method, interviews, indicator or index tools, numerical method, and surveys. The indicator tool is claimed to be the most used in resilience assessment of urban systems. The theoretical framework is viewed as providing a base for methods in resilience assessments. In the assessment of social ecological systems, in which human and ecological systems are considered one integrated system, a flexible assessment method such as the resilience assessment by Resilience Alliance (2010) is considered the most relevant since it can combine the other methods depending on the need. This assessment framework can provide insights into how strategies for addressing change can be developed. This framework has five stages: describing the system, system dynamics, interactions, system governance, and acting on the assessment.

The following chapter discusses the research methodology which was followed when addressing the problem of the study. The research paradigm, research design for each sub-research question, as well as ethical considerations are discussed.

Chapter 3: Research Methodology and Organisation

3.1. Introduction

This chapter unpacks the research methodology used to determine design strategies for informal settlements which increase their adaptive capacity to the impacts of climate change in the context of Eswatini. The study is a theory building and application study with both an exploratory and explanatory purpose.

This study used a mixed-use research methodology with the purpose of developing design strategies that can improve the adaptive capacity of informal settlements to the impacts of climate change. The study followed a pragmatist approach in which the research questions and context are the driving forces determining the most appropriate methodological choice (Nastasi, Hitchcock & Brown, 2010). The following sections explain the paradigm and the methodological approach to address each research question.

3.2. Research Paradigm

This research project sits in a pragmatist paradigm, a philosophy which argues that concepts are only relevant where they support action (Kelemen & Rumens, 2008). According to Saunders et al. (2016), the pragmatism research paradigm originates from the work of Charles Peirce, William James, and John Dewey around the turn of the 20th century. Pragmatism responds to very specific real-world challenges and aims to develop methods to inform practice. The research aims to contribute practical solutions to the defined problem of the study.

A variety of research methods were used in this study depending on the requirement of the research questions, which aligns with the epistemological and ontological requirements of pragmatism. These different methods are either qualitative or quantitative (mixed methods), and the pragmatist research paradigm sees these different methods as complementary (Creswell & Clark, 2017) and relevant. The research questions and employed methods link with each other (as discussed in the next sections) to respond to the main research question of the study.

The purpose of the research emphasises the initial use and prioritisation of qualitative research. This study is both exploratory and evaluative. According to Saunders et al. (2016), an exploratory study is a valuable means to ask open questions to discover what is happening and gain insights about a topic of interest. Generally, the study is structured to meet the purpose of understanding the system of concern (informal settlements), learning from other systems that have addressed similar problems, and building resilience in the system of concern. This study starts by exploring the climate change impacts to which residential settlements should adapt by asking open ended questions to experts involved in climate change issues. Further, the study explores the resilience of a selected informal settlement through observations to build theory. Exploratory research has the advantage of being flexible and adaptable. In this study, the response to each research question is dependent on the findings of the previous research question. Evaluative research on the other hand has the purpose of finding out how well something works (Saunders et al., 2016). The last part of the research proposes design strategies of informal settlements for climate adaptation and evaluates them through focus groups.

3.3. Methodology

The sub-questions, sub-objectives, and methods employed in this dissertation are presented in Figure 3.1 below, and summarised in the paragraphs that follow.

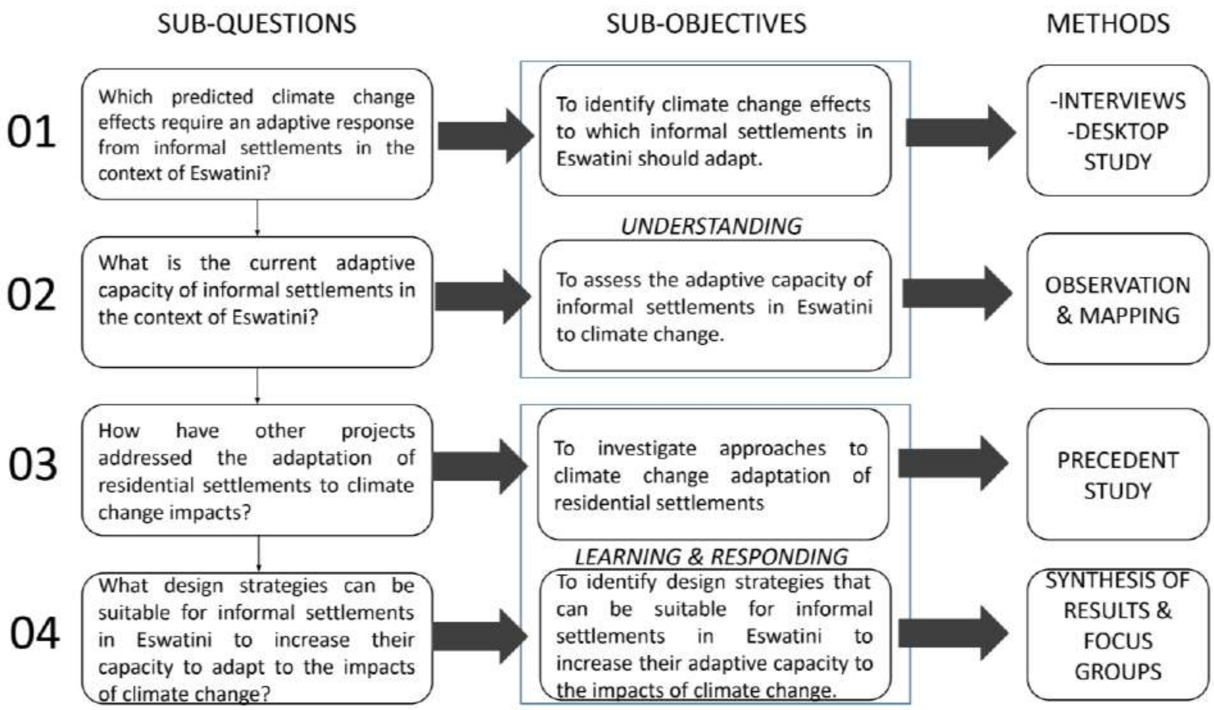


Figure 3.1. Sub-questions, sub-objectives, and methods used in the study

The first research sub-objective which sought to identify climate change effects to which informal settlements should adapt was addressed through interviews with selected experts and a desktop study that was conducted for triangulation purposes. The results identified climatic risks, which created a base for the study to build on. The second sub-objective sought to determine the condition and vulnerability of a selected informal settlement, Msunduza, by assessing the adaptive capacity of the settlement. The third phase of the study (sub-objective three) sought building and settlement design approaches which addressed identified climate change related risks. This section used a precedent study method as well as interviews to complement the findings and for triangulation purposes. All the results were synthesised to develop the design strategies for informal settlements to adapt to climate change impacts. These strategies were evaluated by experts through focus groups for validation purposes.

The methods are discussed in detail in the following sections, and they led to the development of a toolkit of design strategies for informal settlements which can be followed in the development of these areas.

3.3.1. Interviews - Objective 1

Data collection and analysis to respond to the first sub-objective used a qualitative design method. According to Maree (2007), a qualitative study helps in understanding processes underlying various behavioural patterns. Through the use of qualitative methods, this part of the study brought an understanding of the reasons behind the climate change impacts experienced by residential settlements which later informed the design strategies which should be followed to increase the capacity of informal settlements to adapt to climate change.

Semi structured interviews with selected specialists from organisations involved in climate change management (such as National Disaster Management, Municipalities, Eswatini Environmental Authority, Ministry of Tourism and Environmental Affairs, United Nations in Eswatini, and Meteorological Services, among others) and academics, were conducted to identify climate change impacts which affect residential neighbourhoods in Eswatini. Due to the exploratory nature of the study, semi structured interviews were preferred to learn about the reasons behind the answers, and whether participants are well informed about climate change. This research instrument is claimed to be very common since it allows for flexibility, accessibility, and intelligibility, and uncovers certain important hidden aspects, whilst remaining a convenient data gathering technique (Qu & Dumay, 2011). This study identified and confirmed the issues of concern to which the informal settlements should adapt in order to maintain their function of providing affordable services to the urban population. Interviews were also conducted to bring the study to the context of Eswatini.

3.3.1.1. Sampling and target group

Snowball sampling was used in this study to get respondents for the interview. Snowball sampling has been defined as a “non-probability volunteer sampling procedure in which subsequent respondents are obtained from information provided by initial respondents”

(Saunders et al., 2019:817). This method was selected following difficulty in identifying the local population knowledgeable in both climate change and informal settlement upgrading. The required population come from different departments and different disciplines, hence the difficulty in identifying them. Participants in this study volunteered to be part of the research rather than being purposively selected.

Table 3.1. Sample of participants

Participants	Profession	Field	Experience/role
A	Environmental health specialist	Housing sector	Environmental assessment at a government parastatal. Involved in Climate change mitigation and adaptation strategies at National Level [with government ministry]
B	Meteorologist	Weather and climate	Climate monitoring for a government ministry. Monitoring and reporting on extreme climate, making climate summaries, annual climate summaries and similar work.
C	Health Inspector	Housing sector	Public and environmental health. Participate in stakeholder engagements for climate change at national level.
D	City Planner	Town Planning	Town planning. Use of town planning scheme as a regulatory document
E	Maintenance Engineer	Civil Engineering	In charge of infrastructure maintenance in the whole town. Construction of new roads, new infrastructure, maintenance of roads, scrutiny of architectural documentation.
F	Environmental and Public Health Specialist	Environmental and Public Health	Ensure health and safety of residents. Ensure preservation or avoiding pollution to any natural resources.
G	Disaster Risk Coordinator	Disaster Management	Creating awareness about disasters, risks and mitigation in communities. Coordinate stakeholders in all that relates to addressing disasters. Engaged in climate change forums to inform policy
H	Climate Change consultant	Climate Change Unit/ academia	Consultant for government, NGOs, UNDP, SADC on climate change related issues. Prepared Technology Needs Assessment for Eswatini. Author of the Climate Change Yearbook for SADC. Prepares Climate Change proposals for funding. A researcher and academic. Nationally Determined Contribution for Eswatini Coordinator (climate change action plan for Eswatini) - [NDC]
I	Environmental and Public Health Specialist	Environmental and Public Health [Town Board]	Scrutiny of Architectural Documentation. Look at the public health and safety issues, like ventilation, and drainage systems within residential plots. Addresses drainage issues for commercial buildings. Sits in the technical working group of NDMA, and prepares disaster risk management plans
J	Disaster Risk Manager	Disaster Management	Prevent risks, prepares the region for any impending disaster, coordinates any kind of a response to any disaster that has occurred, and coordinates recovery ultimately. Rehabilitates bridges whereby they have been affected by rainfall. Works on food response during droughts, which now occurs annually. Works with the Red Cross on cash transfers and also works with World Vision.

The initial contact was made with a known expert knowledgeable in general climate change issues from the Climate Change Unit at the Ministry of Tourism and Environmental Affairs (MTEA), in Eswatini, who further identified other participants. These participants further identified more participants until saturation was reached. This occurred after thematic redundancy was observed in the first seven participants. Table 3.1. above presents the sampled participants with their experience and roles in issues related to climate change.

The participants represented different professions such as planning, disaster management, academia, environmental management, climate analysts, and engineering. This can be referred to as the group that responds to climate change impacts affecting the built environment. The representation of the different disciplines (or responders) ensured that a holistic picture about climate change impacts was provided from almost all affected disciplines in the built environment. The residents who are affected by the impacts were not engaged due to accessibility issues and the assumption that the residents' responses can be compromised by their expectations of assistance.

3.3.1.2. Data Collection

A pilot interview was conducted before starting the final interviews to gather feedback and modify the interview questions where required. The qualitative interviews were conducted using an interview guide which has a list of topics that were covered in the interview session (Appendix A). Advantages of a semi-structured interview are mostly the flexibility to explore issues that were not considered, or which arose spontaneously during the interview, and sensitivity to participants (Knight & Ruddock, 2008). This helped in understanding the position of the participants in depth.

Interviews were conducted in workplaces of the participants, and it averagely took forty-five minutes to complete the interview. A voice recorder tool was used to collect raw data to ensure the researcher solely focused on the interview. This data was later analysed with the spoken words being converted to written text. After transcription, the analysis process which used thematic analysis technique, resumed. All the recorded interviews were word processed and formatted before being coded. Each answer from the interview questions was coded for a qualitative content analysis which looked for similarities and differences in the responses.

3.3.1.3. Data analysis

The study used thematic analysis through the use of an abductive approach - starting the analysis with theoretically derived themes (expected climate change disturbances) which were then modified as the data set was explored.

Manually transcribing the interview allowed the interviewer to become familiar with the data and allowed ease of identifying recurring themes and patterns in the data. Upon identifying fragments of the data with similar meanings, the data was categorised through coding for ease of managing the data. Such codes were derived from existing theory (a priori) but developed inductively from the data collected during the process of familiarisation of data. The search of themes fully began after coding the data to search for patterns and relationships in the list of codes to create a short list of themes. The term 'theme' is defined by Saunders et al. (2019:657) as "a broad category incorporating several codes that appear to be related to one another and which indicates an idea that is important to your research question". This exercise was conducted using sticky notes which described identified themes. Results of the analysis of each question were summarised in a table format and then discussed with the use of quotations of the verbal responses from the interviewees.

3.3.1.4. Trustworthiness

Lincon and Guba (1985) presented a criterion for developing trustworthiness: credibility, dependability, confirmability, and transferability. In this section and the sections that follow, it is highlighted how trustworthiness was developed for each method.

In this part of the study (interviews), credibility of the data was ensured through triangulation by using a literature review, which included grey literature, to confirm the disturbances to which residential neighbourhoods should adapt. The findings from each method were compared to draw conclusions. Further to this, member checking was conducted. Interpretations of the data were shared with the participants to verify their intentions and clarify where required.

To establish dependability, an inquiry audit was conducted where an external researcher examined the data collection method, data analysis, and findings of the study to ensure the findings aligned with the raw data collected.

The policy and economic context of Eswatini, as well as the climate and climate adaptability condition of selected neighbourhoods in Eswatini is provided in the study. This allows accuracy in judging the transferability of the study. Further, a description of the type of informants used in the study was given.

Confirmability was exhibited by recording interviews, transcribing, and further highlighting portions of the transcribed recordings of participants that depicted emerging themes. An audit trail was conducted by describing how data was collected, analysed, and interpreted. Notes were taken concerning observed unique behaviour or influences of the participants, and a rationale was recorded on the reasons for reaching the conclusions. A reflective journal was used to record feelings of the researcher on what was observed in the duration of the study.

The results of this part of the study categorised the climate change impacts into impacts on buildings, impacts on infrastructure, impacts on the natural environment, and impacts on social life. Further, this enabled identification of components of the system which should respond to keep the system (settlements) functional, even when impacted by the identified effects. This informed the observation study discussed in the next subsection.

3.3.2. Observational Studies and Mapping - Objective 2

Data collection and analysis to answer the second sub-objective to establish the adaptive capacity of informal settlements, used a quantitative design method to collect and analyse data. A structured observation checklist data collection tool was used. This structured observation checklist was developed based on the results from sub-question one using an abductive approach. The components expected to respond to climate change impacts to keep settlements functional formed the variables of the resilience assessment. Infrastructure, buildings, and resources are affected and therefore their vulnerability was assessed through assessing the subsystems which keep them functional. The contents of the structured checklist that was used during the observational studies were therefore informed by the interview study.

The observational checklist was used to collect data on the physical condition and spatial design of the selected informal settlement to determine its adaptive capacity to climate change. Observation of the physical state of the informal settlement is understood in this study as indirectly acquiring evidence of the conscious behaviour or choices of stakeholders previously made with regards to realisation of the settlement. The study therefore looked for physical traces, in different categories informed by the precedent study, to establish general patterns of informal settlements in Eswatini in relation to their climate change adaptive capacity. Observation of physical traces is described by Zeisel (2006) as 'investigation of the physical condition of the environment to understand previous activity not produced for it to be measured by the researcher.' Other devices used for capturing data included: a camera, diagrams and topographical maps.

3.3.2.1. Study area identification

Msunduza Informal Settlement located in Mbabane, Eswatini, was purposely selected as a study area in the research project. This area was chosen for the following reasons: its rapidly changing nature; being subject to significant development pressures; being the oldest informal settlement in Eswatini; because it was selected as part of the Urban Development Program (UDP) which aimed to upgrade selected informal settlements in Eswatini; and because of its accessibility to the researcher. This settlement presents all the characteristics of an informal settlement as described by literature (Bredenoord, 2016:1; Nassar & Elsayed, 2017): lack of basic infrastructure, lack of security of tenure; and low quality, overcrowded and inadequate housing. It was assumed that this settlement would be a good representation of informal settlements in Eswatini. The criteria for selection, therefore, included the following: informal settlement that has or is currently undergoing upgrading; informal settlement in the global south; accessible informal settlement; and informal settlement the researcher is well familiar with.

3.3.2.2. Data collection

Data collection used abductive mapping processes to link the data with the spatial structure of the settlement. The first phase of this study was to identify and locate the vulnerable neighbourhood components and systems with the potential to absorb and adapt to climate change disturbances at settlement level (water management systems, services, as well as the urban morphology and land use of the study area) and at building level (building facade components, interior components, structural components, building services, typology, among others) through mapping for further analysis. The responding components under each category (building, infrastructure and resources) are presented in Figure 3.2, and further broken down according to the variables through which their resilience was assessed, determining the existence of diversity, redundancy, modularity, or connectivity. This provided an assessment framework for informal settlement resilience.

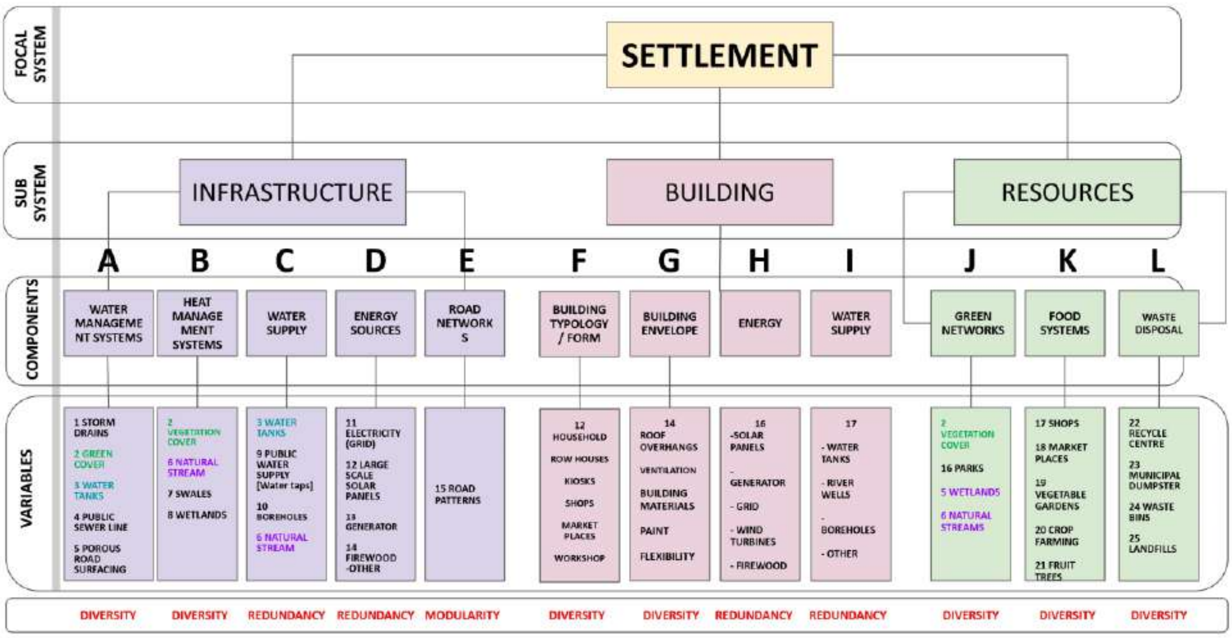


Figure 3.2. Informal settlement assessment framework (developed from the work of Peres, 2016)

The variables were defined in the observation checklist (Appendix B) for ease of identification. This checklist with clearly specified components and variables (also shown in Figure 3.2) as well as their expected conditions, was used by the researcher to capture the location of these components and further record their condition. This being a quantitative study, the checklist was developed and tested through a walkabout that was aimed to ensure that the checklist covered all components that have the potential to address adaptation to climate disturbances.

At building level, a sample of the buildings was used to draw a conclusion about the resilience of the target population. Target population is known as the population which is the actual focus of the inquiry (Saunders et al., 2016:274). The target population for this study was houses located at Msunduza informal settlement. This study used probability sampling which consists of simple, systematic, stratified, and cluster sampling. Probability sampling is when cases have an equal chance of being selected for inquiry (Saunders et al., 2016). Systematic random sampling was chosen for this study. It involves the researcher choosing the sample at regular intervals from the targeted sample. The targeted sample for this study consisted of 280 houses in the study area, however 230 houses were observed since saturation was reached at this number. A topographic map of the area was used to identify the sample. The houses were numbered with a unique number and the first house was selected using a random number. Every fifth house was then chosen until the sample of 230 was reached.

The chosen subjects had to meet the following criteria to be included in the sample:

- a building located within the boundaries of Msunduza.
- a completely constructed building.
- a building which is operating/functioning.
- within a homestead with many houses, the main house (or biggest house) was selected.

In the second phase of the study, for every selected component of houses, infrastructure, and resources, the researcher assessed the existence and level of any relevant characteristics of resilience such as diversity, modularity, redundancy, and flexibility. The aim was to establish vulnerable areas and components, the resilience of which should be enhanced.

3.3.2.3. Research instrument

A desktop study was conducted, and the study area was modelled using ArchiCAD software from aerial photographs of the area received from the Ministry of Natural Resources and Energy through the Surveyor General's office. After analysing the site through a desktop study, an observational study was conducted by walking within the site and taking photographs of the settlement components and systems for assessments The data and location of these components (subsystems) were captured using Epicollect5 which is an open-source online documentation tool developed by the Imperial College of London. This is a tool which uses a survey approach to document, geo-locate, and store data using individual cell phones.

3.3.2.4. Data analysis

The data was uploaded onto a single online data repository from which the data was collected for analysis. The spatial dimension of the data was interpreted using QGIS, another open-source GIS programme. Aerial photographic data was used to present the spatial data of the survey. A software used for analysing statistical data, 'Statistical Package for the Social Sciences (SPSS)' was used for basic descriptive statistical analysis. A descriptive survey was chosen as it gives an accurate view of the characteristics and understanding of a certain group under observation. This analysis was used to organise and summarise data using frequency tables and charts such as bar charts and pie charts. The intention was to determine quantities in percentages of variables being measured, such as the percentage of each type of a house or building materials, so that informed decisions are made on which variable needs to be enhanced to build resilience into each subsystem or component.

3.3.2.5. Validity and reliability

In order to establish the quality of the research, the validity and reliability of the research procedure was considered for this phase of the study. The first step was to develop the structured observational checklist and share it with two academics for review. During the data collection process images were taken using the Epicollect5 app which also captured the coordinates of components being observed. The images ensured that there is evidence of the condition being captured for consistency with the data collected. Further, the coordinates ensured that the location of each component is marked to allow for future verifications whenever a need arose. This ensured internal reliability, which refers to ensuring consistency during a research project (Saunders et al., 2016).

The analysis phases used QGIS to interpret the geo-spatial data, while the descriptive statistical analyses were carried out using SPSS. This allowed for quantitative analysis of the data to reveal both the spatial location and relation. The use of photographs and transect walks enabled the triangulation of the results and further qualitative interpretations of the various components.

3.3.3. Precedent Study - Objective 3

Data collection and analysis to respond to sub question three followed a qualitative research design known as precedent study. Since the aim of this study was to learn from any available project addressing climate change adaptation, the precedent study method was deemed relevant for this study. This method used literature analysis to collect data, and precedent analysis technique for analysis.

The precedent study method can be considered a subset of the literature analysis method since literature is consulted to identify precedents and information about these projects. Literature analysis as a research method is one of the most effective research methods used when the aim of the research is to create a solid foundation for advancing knowledge and developing theory (Webster & Watson, 2002). Literature reviews may be the best methodological tool for evaluating theory or evidence in a certain area of study according to Transfield et al. (2003). Several types of literature reviews have been discussed by authors, and this study used a type described by Snyder (2019) as a 'semi-systematic review' or 'narrative review' approach. This approach was determined by the author as most suitable for topics studied by various researchers within diverse disciplines, where it is impossible to review every single article on the topic. It is useful in the overview of topics and looking at how research has progressed or developed over time in that topic (Snyder 2019).

The aim of this study was to learn about the application of climate change adaptation technologies from existing and proposed climate change adaptation projects mostly located in developing countries, and further identify components that respond to climate change in a settlement. This created a foundation for developing design and development strategies of informal settlements, which will have a sufficient adaptive capacity to climate change's impacts, evolve with demands of climate impact, and support the wellbeing of residents.

3.3.3.1. Precedent identification

Literature analysis was conducted on purposely selected grey literature, specifically the document titled, 'A Manifesto for Climate Responsive Design' by Peter Clegg and Isabel Sandeman of Feilden Clegg Bradley Studios on behalf of Enabel (Clegg & Sandeman, 2019). This document contains a collection of climate responsive projects in East Africa compiled after a conference conducted in Kampala, Uganda, on 27 and 28 February 2019 on 'Raising Awareness for Climate Responsive Design in East Africa'. This document was purposely selected for study since it meets the following precedent selection criteria: a collection of climate responsive design strategies in developing countries, use of affordable building technologies in the designs, availability of the precedent publicly, projects peer reviewed or presented in a conference, precedents in a similar context as the study area, and a document known and readily available.

The precedents selected for study seemed to mainly address overheating impacts, possibly because of their location (East Africa) where overheating is the main concern. This study was therefore extended to complement the technologies reviewed in Clegg and Sandeman (2019), and for purposes of triangulation. Ten more precedents were purposely selected through

Google search and Google Scholar using the search terms 'climate change responsive designs'. The first ten precedents located outside Africa (Asia, Europe, South America) and addressing impacts of flooding and storms were selected. One of the precedents comes from a developed country (Denmark), however some of the nature-based climate responsive technologies applied were considered relevant even for use in informal settlements in developing countries.

3.3.3.2. Data Collection

A standardised means of abstracting relevant information from the grey literature was used to answer the research question. This information was mainly abstracted from sections that discuss climate change adaptation in the selected documents. A thematic or content analysis technique with pre-existing themes developed from preliminary literature review and interviews was used to identify, analyse, and report patterns in the form of themes that were abductively developed. The data collected was presented in tables with content about climate change adaptation technologies implemented in that precedent.

The data collected was complemented with data collection through interviews with the experts selected to respond to the first sub research question as discussed in the previous section. The same experts were asked open ended questions on what could be done to adapt the residential settlements to climate change impacts. This data was also recorded and transcribed for further analysis.

3.3.3.3. Data Analysis

A thematic approach was used to search for themes or patterns of recorded climate change adaptation technologies for both the precedent study and interviews. A thematic approach is known to offer a systematic and orderly way of analysing qualitative data (Saunders, Lewis & Thornhill, 2016). It helps a researcher to "integrate related data drawn from different transcripts and notes and identify key themes or patterns from a data set for further exploration" according to Saunders et al. (2016:579).

The analysis used a combination of a deductive and inductive approach by firstly developing themes derived from existing theory and part of the data, which was further modified as the collected data set was being explored. A template for analysis with a list of themes was used as the main tool for analysing the data. The themes used were categories of technologies and design strategies implemented in the selected precedents, these being technologies responding to flooding, overheating, storms, and drought. Technologies which were implemented for each category were recorded for each precedent. These technologies recorded for all precedents were then synthesised to identify summarised technologies and strategies the study could learn from. The deductive approach was used to act as a guide to the analysis, and the inductive approach was used to ensure new emerging sub-themes of climate change responsive technologies were identified and included, and to escape limitations to themes developed from existing literature.

3.3.3.4. Trustworthiness

The credibility of the data for this section of the study was ensured through triangulation by using the precedent study and interview methods to identify some of the climate responsive design strategies. Triangulation in this case, however, was aimed at complementing the two methods and findings from each method to get to conclusions. As discussed in Section 3.3.1, member checking was conducted through sharing interpretations of the data with the participants to verify their intentions and clarify where required.

In this section and all other methods, dependability was established through an inquiry audit where an external researcher examined the data collection methods, data analysis, and findings of the study to ensure the findings aligned with the raw data collected.

The areas of expertise of the interview participants is given in the study to allow the reader to judge the transferability of the study. Further the context of each precedent was presented before data was extracted for each precedent to allow the reader to determine the transferability of the study.

Similarly, as the method used to address the first sub research question, confirmability was determined by recording interviews, transcribing, and further highlighting portions of the transcribed recordings of participants that depicted emerging themes. An audit trail was conducted by describing how data was collected, analysed, and interpreted. Notes were taken concerning observed unique behaviour or influences of the participants, and a rationale was recorded on the reasons for reaching the conclusions.

3.3.4. Focus Groups - Objective 4

The aim of this part of the study was to identify design strategies that can be suitable for informal settlements in Eswatini to increase their capacity to adapt to current and anticipated impacts of climate change. The response to this part of the study informed the design toolkit, therefore, this sub-question contributed in responding to the main research question of this study. The results from the first three sub-research questions and explorations of resilience theory informed the proposed strategies which were reviewed through focus group discussions.

Focus groups were the final method that was used to review the design strategies and get opinions from participants. The groups consisted of carefully selected suitable specialists in academia, government, built environment industry, parastatal, and municipalities. The researcher acted as facilitator of the focus group discussions. The sessions were recorded for further analysis.

The purpose of the discussion was to review (consult on) preliminary proposed design and development strategies, and generate ideas intended to increase the capacity of informal settlements to adapt to current changing impacts of climate change. Prior to these discussions, participants were given a list of the strategies to evaluate the suitability to informal settlements. The main aim was to get the participants to familiarise themselves with the long list of strategies and prepare them for the discussions. The results of the individual evaluations were also considered to complement the results of the focus group discussions.

A schedule was created to act as a guide and ensure all ground is covered. The schedule followed an outline given by Breen (2007) with the following stages:

- Welcoming of participants
- An overview of the topic – the moderator gave a clear picture of the current situation which led to the important topic and question.
- Statement of the ground rules of the discussions, and assurance of confidentiality
- Presentation and discussions - the moderator used guiding questions to guide the discussions beginning with general experiences and progressing to specific problems. The researcher spent most of the time probing questions which started with general experiences and determining the extent to which they agree with some issues of climate change and climate change adaptation. This acted as a warmup time. The participants were then engaged to answer the key research questions.
- Conclusion/summary

3.3.4.1. Selection of participants

Participants for the focus groups were selected using snowball sampling to ensure that the relevant stakeholders are selected to contribute to the development of the designs strategies of informal settlements adapting to climate change impacts. The first participant that was purposely selected is an experienced professional architect who is involved in the development of low-cost housing. He is also responsible for managing an architectural firm. The consultant was deemed the right person to start recommending other participants that can make relevant contributions looking at the role and experience of this consultant. There were 8 participants that were eventually selected coming from academia, disaster management agencies, the private sector (architects and a planner), and municipalities (Table 3.2). After selection of the participants, they were sent invitations which provided an introduction to the study, detailing what was expected of them and the importance of the research to Eswatini, noting that the discussion will be recorded, and assuring confidentiality. The discussions were conducted virtually through Google Meet. This platform was preferred to accommodate experts that were not locally available at the time of the discussions.

Table 3.2. Sample of focus group participants

Participants	Profession	Field	Experience/role
A	Architect	Architecture	Consultant: provision of architectural and project management services. Participant is a co-director of an architectural firm.
B	Academic	Education	Lecturing in the Architecture Department of a certain institution. The participant is also a Head of Faculty of Design in the institution.
C	Environmentalist	Environmental and Public Health	Ensure health and safety of residents. Ensure preservation or avoiding pollution to any natural resources.
D	Senior Architectural Technologist	Architecture	Provision of architectural services in an architectural firm in Eswatini.
E	Urban Planner	Municipality	Chief Urban Planner in one of the cities in Eswatini, responsible for managing spatial planning of the city.
F	Environmentalist	Environmental Health	Look at the public health and safety issues.
G	Disaster Risk Coordinator	Disaster Management	Creating awareness about disasters, risks and mitigation in communities. Coordinate stakeholders in all that relates to addressing disasters. Engaged in climate change forums to inform policy
H	Architect and academic	Architecture and Education	The participant is a consultant rendering architectural services, and also an academic in the Architecture Department of one institution

3.3.4.2. Data Collection

Prior to the focus group discussions, participants were given evaluation forms (Appendix D) to assess the suitability of the proposed strategies individually. The participants were given criteria to use which used a five-point Likert scale (5-very high, 4-high, 3-neutral, 2-low, 1-very low) to assess the constructability, affordability, acceptability, regulatory, and effectiveness of each strategy. This exercise gave the participants an opportunity to think deeply as they familiarised themselves with the strategies.

After the short survey was conducted, the participants convened for discussions. During the discussions, participants were expected to share and compare their experience on climate change adaptation together, review and evaluate the proposed design ideas that will increase adaptive capacity of affordable housing and explore issues of shared importance. The discussions were tape recorded for ease of analysis.

3.3.4.3. Analysis

During the analysis of the discussions, arising themes, important quotes, and unexpected findings were noted. The list of what was expected as outcomes from the discussions were matched with the actual outcomes of this study. Atlas.ti software was used for analysis as it makes it easy to assign codes to emerging themes and merge them where necessary. The themes were given reference numbers and frequencies of codes (or themes) and calculated. The extent to which participants agreed/disagreed on issues was tested. To ensure reliability, an independent researcher was engaged to cross-check the codes. The frequency of a shift to an opinion was as well analysed, and conclusions were made on the agreed strategies. Tables and maps were used to present the results.

3.3.4.4. Trustworthiness

The credibility of the data for this part of the study was ensured through evaluation of the findings by focal groups. The output of the study (toolkit of design strategies) was evaluated through a survey where participants of focus groups were provided a list of the design strategies to rate their effectiveness, constructability, affordability, acceptability, and regulatory. Further, these strategies were discussed through focal groups before the output was finalised. The focal groups ensured member checking as the participants discussed and clarified their rating of the design strategies.

Dependability of the data was also ensured through the focus group discussions. The discussions provided an opportunity for the participants to inquire and examine the data collection methods, analysis, and findings that led to the list of the design strategies. This inquiry occurred following a presentation conducted to participants by the researcher.

The selection criteria and areas of expertise of the focus group participants is provided in the study to allow judgement of the transferability of this part of the study. The climatic condition and climate change effects of the study area are provided in the study, which also allows judgement of the transferability of this part of the study.

Finally, confirmability was determined through recording the focal group discussions, transcribing, and further coding themes that arose. Observed unique behaviour or influences of the participants were recorded to clarify how the conclusions were reached.

The synthesis of findings from the four sub-questions enabled the development of a toolkit of design strategies that would be suitable for informal settlements in Eswatini to adapt to the impacts of climate change. The different sub-questions acted as filters to devise this toolkit. The first filter was to identify the specific climate change risks to limit the strategies in the toolkit to those that address the identified issues. The second filter was to identify the vulnerable areas and components of informal settlements which require enhancement. A set of strategies from international (outside Africa) precedents that would respond to the risks and vulnerability and allow settlements to adapt to them were identified. Lastly, a filter was setup to determine which of the strategies would be suitable for Eswatini context through focus groups. The lists of strategies identified to be suitable for this context formed part of the design toolkit aimed for officials responsible for upgrading informal settlements and residents of informal settlements, to respond to the main research question of the study: “What design measures can be taken to improve the capacity of informal settlements in Eswatini to adapt to the impacts of climate change?”

3.4. Ethical considerations

Letters of requests to conduct research were issued to organisations which allowed the researcher to interview their employees. Potential participants were approached and briefed about the study and further given a choice to accept or decline to participate in the study. Participants who gave consent to partake were issued a consent form to sign. Participants were given a choice to decide whether they can be recorded or not. During data collection (interviews), identities of participants were not recorded. Data collected through interviews was encrypted and stored in a secure cloud server. No individual identities were used in any reports or publications resulting from the study. Ethics approval was received from the Ethics Committee, University of Pretoria (Appendix E).

3.5. Conclusion

This research design set out to determine design strategies that could be used in informal settlements to increase their adaptive capacity to climate change. The main research question of the study was divided into four sub-questions. The first sub-question (sub-question A) considered establishing the climate change impacts to which informal settlements should adapt. This was conducted through semi structured interviews with experts involved in climate change related issues in Eswatini where the study area, Msunduza informal settlement, is located. The second research objective was undertaken to establish the adaptive capacity of informal settlements through an observation study (field work) of a selected informal settlement (Msunduza). The resilience assessment of the study area used the Epicollect5 online data collection tool, and QGIS was used to interpret the spatial dimension of the data. The vulnerability of the informal settlement was documented. The third research objective which aimed to investigate approaches to climate change adaptation of residential settlements used a precedent study method. This method used literature analysis to collect data, and precedent analysis technique for analysis. Precedents were purposely selected through Google search and Google Scholar using the search terms, 'climate change responsive design', 'climate change responsive buildings', 'climate change design', and 'climate change adaptation design'. The final research objective aimed to determine design strategies of informal settlements which can be implemented to increase the adaptive capacity of these settlements to climate change. These strategies were determined through synthesis of findings from the three sub objectives of the study. The strategies were further evaluated through focal groups.

Finally, the toolkit of design strategies was determined by collating and interpreting the findings from the preceding three research phases. The focus group discussions reviewed the preliminary proposed design strategies and their ideas refined and generated final ideas intended to increase the climate change adaptive capacity of informal settlements.

The following chapter presents the study area's context.

Chapter 4: Msunduza as the context of the research

4.1. Introduction

The research was undertaken in the Msunduza informal settlement. This is one of the first informal settlements in Mbabane, the capital city of Eswatini, and has undergone dramatic changes in recent years as a result of increased natural disasters, outbreak of diseases, and most recently, upgrading through the Urban Development Programme (MHUD, 2007; MTEA, 2011; MTEA, 2016). Mbabane is one of the major, fast growing cities experiencing rapid urbanisation in Eswatini, which has resulted in the formation of informal settlements.

This brief chapter provides understanding of the context of the study. It starts by discussing the location and general economic, geographical and climatic context of Eswatini. Finally, Msunduza in its current condition is discussed. This chapter is not exhaustive in any way, but rather sets out to give a short description of the larger context within which the study was undertaken.

4.2. Eswatini context

The study area is located in Mbabane, a city severely affected by the impacts of climate change in Eswatini. Eswatini, a culturally rich country formerly known as Swaziland, is a landlocked country covering 17,200 square kilometres of area and has an elevation range of 600-1,860 metres above sea level (World Bank, 2020). The country is in southern Africa, bordered by Mozambique on the east and South Africa on the north, west and south (Figure 4.1). Eswatini, known to be a mountainous country, hosts a wide variety of landscapes, from mountains along the South African border to savannas in the east and rain forest in the northwest. The country consists of three geographical regions which are the Highveld, Middleveld and Lowveld. The capital city of Eswatini, Mbabane, is in the Highveld which is mountainous.

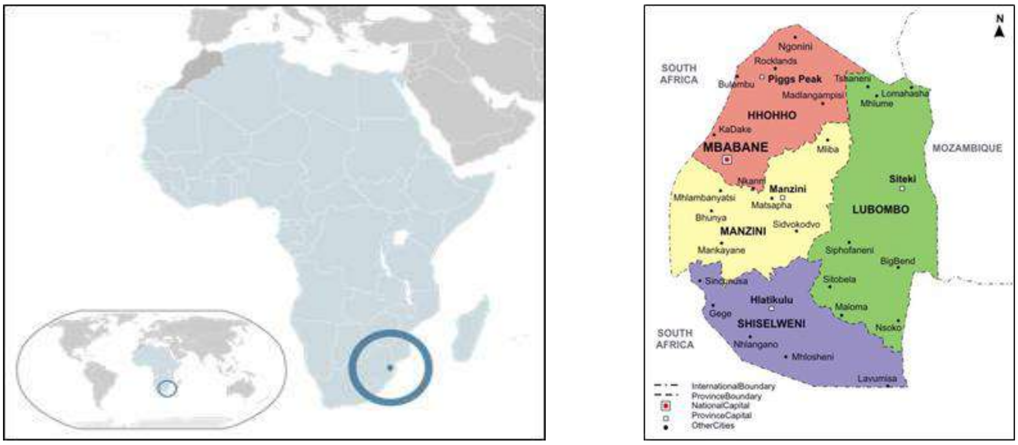


Figure 4.1. Eswatini location (Alvaro, 1984)

The main economic activities of Eswatini, include agriculture, forestry, mining, manufacturing, tourism, and government services, with the majority of the population engaged in subsistence agriculture. The varying rainfall patterns are already affecting agriculture by reducing crop yields according to the Swaziland Annual Vulnerability Assessment and Analysis Report (Assessment Committee, 2019).

Eswatini has a subtropical climate (varying from tropical to near temperate), with wet summers from October to March, and cold dry winters from April to September. The rainfall received in summer is about 75% of the annual rainfall, and it is normally accompanied by thunderstorms. The range of rainfall collected is 500mm in the southern lowveld to 1500mm in the northern highveld (MTEA, 2011). Rainfall tends to vary from one year to another. This may lead to flooding in some years, and droughts in other years. The average annual temperature is 17°C in the highveld to 22°C in the lowveld. These temperatures, according to the Ministry of Tourism and Environmental Affairs, are zonal averages with variations across zones. The temperature in the highveld remains temperate, while in the lowveld it goes up to 40°C in summer.

The country is facing severe climatic changes which have resulted in several effects in cities and forced the country to respond to those impacts. The climate change impacts and country response to the impacts is discussed in the following section.

4.3. Climate change in Eswatini

Eswatini has contributed very little to greenhouse gas (GHG) concentrations in the atmosphere, which is less than 0.002% of global emissions (MTEA, 2015). However, the country is highly vulnerable to climate change due to her social-economic and environmental context (MTEA, 2016). Eswatini, like other southern African countries, is very sensitive to changes which worsen the limited resources the country has available (MTEA, 2015). The country is exposed to severe climate change impacts, with variable precipitation patterns, droughts, desertification, higher temperatures, and increased storm intensities having already impacted the country's key economic sectors.

According to the Eswatini National Climate Change Policy of 2016, the main effects of climate change are flooding due to the increasing variable precipitation events and increased storm events, biodiversity alterations also due to the shift in rainfall patterns and rising temperature, increased morbidity and mortality due to heat stress and cold stress, and biomass availability/depletion (which the low-income population group depend on) due to drought

(MTEA, 2016). Most impacts on infrastructure seem to result from flooding in Eswatini, especially in urban areas. The risk of flooding increases with the increase in frequency of severe precipitation events. Flooding affects infrastructure, movement and economy of the country.

Climate change is expected to disproportionately impact the poor living in vulnerable areas such as informal settlements. The effects are on water, food, fuel, health, education, provision of affordable housing in the city, and access to social services. The country has very little capacity to cope with these impacts. As such, climate change has now been considered a priority development concern, and the country is attempting to take actions to reduce vulnerability of its people and risks to national development (MTEA, 2015).

The national response to address climate change includes policy and strategic responses. Eswatini has developed a series of climate change actions which include the establishment of a multi-stakeholder National Climate Change Steering Committee (NCCC) in 2011 with the aim of ensuring effective coordination of climate change across sectors, and liaising with other relevant stakeholders in developing climate change initiatives in Eswatini. This is the committee which has spearheaded the development of Eswatini's 2014 National Climate Change Strategy and Action Plan, as well as the 2015 National Climate Change Policy (NCCP). The government of Eswatini developed a National Climate Change Strategy and Action Plan (NCCSAP) for the period 2015-2020, with assistance from the United Nations Development Programme (UNDP) and the Common Market for Eastern and Southern Africa (COMESA). The aim of the NCCSAP is to deal with the unfavourable effects of climate change systematically in a way that will also contribute to sustainable development, eradication of poverty, and the improvement of adaptive capacity for the country. The NCCSAP is taken as the implementation framework of the 2016 NCCP.

The goal of the NCCP, according to MTEA (2015:1), is to "support the development of a sustainable, climate resilient and inclusive low-carbon green growth economy in line with vision 2022 outlined in the national development strategy." It has been developed "to provide the enabling framework to guide Swaziland to address the challenge posed by climate change" (MTEA, 2016:09). This framework is also claimed to provide an enabling environment for communities to propose activities which will assist in eliminating poverty and contribute in building a climate-resilient country. The policy is a step towards adapting to climate change, build resilience in key climate sensitive sectors, and minimise the costs of unavoidable impact of GHG emissions. The policy focuses on adaptation but does not ignore the importance of joining the global community in GHG mitigation efforts.

Key areas in Eswatini which have been highlighted by the NCCP as vulnerable to climate change are: water resources, biodiversity and ecosystems, health, tourism, energy, infrastructure, and traditions and customs. The policy, however, seems to focus on building resilience in the agriculture sector, as it is claimed to be a critical mainstay of local livelihoods and also contributes 9.5% of the country's gross domestic product (GDP). Agricultural production, which is at risk of declining is therefore seen as the key to cushion against effects from climate change.

The current climate change policy of 2016, however, does not clearly discuss adaptation of the built environment (mostly cities), yet globally the built environment is claimed to be responsible for a third of global GHG emissions (Zari, 2008) as a result of construction of buildings, consumption of resources, creation of waste, and emission of pollution during the life cycle of the buildings. Most of these emissions come from cities, which are also more vulnerable to the effects of climate change (Ndebele-Murisa 2020), and this is likely to increase in southern African cities, including Eswatini (Broto, 2015; Childers et al., 2015; Muchandenyika, 2015; Ndebele-Murisa et al., 2020).

Sectoral policies and legislation have also been developed through the key sectors of the economy which are impacted by climate change to respond to the impacts resulting from climate change in the different sectors, among other reasons. Some of the policies and legislation include: Environmental Management Act of 2002 (GoE, 2002), National Disaster Management Policy of 2010 (NDMA, 2010), Swaziland National Disaster Management Plan of 2000 (GoE, 2000), and National Disaster Management Act of 2006 (GoE, 2006). According to a vulnerability assessment report prepared by the Ministry of Natural Resources and Energy (MNRE) in 2014, Eswatini has a vast number of policies and institutional structures related to aspects of climate change, but they do not seem to be climate change specific. They can be criticised for focusing on and addressing anthropogenic activities which exacerbate climate change, and not sufficiently addressing impacts posed by future climate change.

4.4. Msunduza as the main context of the study

Msunduza, an informal settlement located in Mbabane, in the Hhohho region, Eswatini (Figure 4.2), forms the exploration ground for this study. Msunduza is the most densely populated and oldest informal settlement in Eswatini (Ndlela, 2005), therefore the study assumes it will give the most accurate information on the condition of informal settlements in Eswatini in terms of their adaptive capacity and give possible solutions which can be replicated in other settlements facing similar challenges and history in similar contexts. This area was also selected for study as it was one of the areas prioritised for the upgrade done through the Urban Development Program (UDP) launched in 1994. The UDP aimed at formalising these areas by installing basic infrastructure and allocating leases to residents. However, over 60% of this area is still informal as a majority of the residents have not been able to pay the development fees for them to receive title deeds (MNRE, 2018) and receive municipality services.

Figure 4.2. Location of Msunduza

Msunduza, which is divided into five neighbourhoods namely, Mntulwini, Gobholo, Mncozini, Mncitsini, and Maqobolwane; covers about 145 hectares and holds about 1 885 households or about 13 households per hectare. Currently in this area there are 1 828 plots divided during the UDP, however out of these, 500 are vacant, 400 have been formalised, and 700 are informal. The sampled plots for study exclude the vacant plots and this makes a population of 1 100 plots. Figure 4.3 below presents only the focus area for study giving a sense of size and distribution of buildings within the boundaries of the settlement. The houses are clearly dense at the centre of the settlement and sparsely distributed towards the south of the settlement. There is also a random distribution of buildings on the central portion, while towards the south, the buildings follow the main streets. Formal order of distribution is also observed on the western side of the settlement which connects to the formal city (Mbabane).

Figure 4.3. Msunduza map

Attempts to address climate change effects require more adaptation than mitigation strategies as mitigation will have less effect locally, even though it will contribute to global attempts at reducing GHG emissions. A good starting point would be addressing the basic needs of humanity: shelter adaptation, ensuring food security, and adaptation of water sources to ensure survival of humanity, especially in vulnerable areas. Adapting vulnerable areas such as informal settlements to the impacts of climate change is vital for humanity to thrive. Communities exposed to the impacts of climate change struggle to recover after being affected, especially in the absence of external assistance (from government or NGOs). In the 2015-2016 El Niño, for instance, over 500 homesteads were damaged by storms in Eswatini; however, they did not receive assistance (MTEA, 2015). Some of the affected homes required rehabilitation and most required reconstruction altogether (MTEA, 2015). Informal settlements, in the context of Eswatini, are mostly affected by impacts of climate change deteriorating their functionality and are under threat of eventual malfunction as a result. The effects on informal settlements will exacerbate the housing crisis in urban areas and further increase poverty. Resilience should be built into existing and future houses to ensure continuous and better functioning of these settlements even in the midst of perturbation. The MTEA (2016) provides for this under the policy statement, “promote better design and standard construction of houses, industrial areas and infrastructure”.

4.5. Conclusion

The study was undertaken in an informal settlement, Msunduza, located in Mbabane, the capital city of Eswatini. This is a country faced by the effects of climate change which are mostly affecting informal settlements, as evidenced by the high number of homesteads which were affected by El Niño and recent climatic events. Eswatini, which forms the larger scale of the study, has a subtropical climate (varying from tropical to near temperate), with wet summers from October to March, and cold dry winters from April to September. The unstable climate in this context has affected the critical economic activities of the country, more especially agriculture, which has resulted in response through policies and legislations.

The NCCSC, established in 2011, spearheaded the development of the National Climate Change Strategy and Action Plan in 2014, as well as the 2015 National Climate Change Policy (NCCP). The aim was to address the unfavourable effects of climate change in different affected sectors and further achieve sustainable development goals which include addressing poverty.

Msunduza informal settlement was selected for study as it is the most densely populated and oldest informal settlement in Eswatini, making it more vulnerable to the impacts of climate change (Ndlela, 2005), and was therefore prioritised for the Urban Development Programme (UDP). The UDP aims to formalise the identified informal settlement areas by installing basic infrastructure and allocating leases to residents. This programme provides an opportunity to address the climate change effects through building resilience in the settlement while aiming to achieve sustainable goals and function of the settlement.

PART II: RESEARCH

Chapter 5: Climate Change Impacts in Eswatini

5.1. Introduction

Climate change impacts the cities we live in and conversely, cities contribute to climate change as a result of resource consumption, transportation, construction of buildings and greenhouse gas emissions created throughout the life cycle of buildings and infrastructure (Huovila et al., 2009; Magwood, 2014; Ndebele-Murisa et al., 2020; Zari, 2008). This dictates an urgent need to devise new human settlement design strategies to limit the impacts on the natural environment and to improve the resilience of human settlements to unavoidable climate change impacts. With the study's focus on devising design strategies to ensure continuous and even improved functioning of informal settlements despite climate change disturbances, it is important to first understand how residential neighbourhoods may be affected by climate change.

As a first step towards understanding the climate change disturbances to which residential neighbourhoods in Eswatini should adapt, different experts, drawn from academia, municipalities, independent climate change consultants, government and parastatals, were interviewed. These were identified through snowball sampling to get a holistic view from the experts addressing climate challenges in different sectors. The experts were interviewed through a semi-structured interview (Appendix A) which had three sets of questions regarding the different elements of expected climate change effects: temperature changes and their effects, precipitation changes and their effects, and wind changes and their effects, with the intention to ensure that participants respond about all the elements of climate which are changing. The interviews collected observations from the experts regarding how the climate is changing in Eswatini and what they have observed as effects of these changes on neighbourhoods. The selected experts were presumed to have all the required information based on their professions and experience.

The study used thematic analysis using an abductive approach to analyse the data as discussed in Chapter 3. The analysis started with theoretically derived themes which were temperature change disturbances, precipitation change disturbances, and wind change disturbances (Figure 5.1). Under these themes, new sub themes developed as the transcribed and coded data was explored. The data collection method, data analysis and findings, as presented in this chapter, were examined by an external expert reviewer to ensure alignment and dependability of the data and findings. The themes and sub themes identified are presented in the sections below.

Figure 5.1. Thematic analysis of data using sticky notes

This chapter presents results from the interviews, followed by a discussion of the findings, concluding with a summary of identified climate change effects to which informal settlements should adapt.

5.2. Climate Change in Eswatini

Participants, upon giving consent to participate in the study, were firstly questioned about the climatic changes in Eswatini mainly based on their observations. This was to establish a baseline of their understanding of climate changes and thus to determine the reliability of their responses, and to establish how climate change is viewed by the experts from different fields affected by climate change. It is logical that if experts are not well informed about climatic changes in Eswatini, they will not be able to give accurate responses on how climate change affects residential neighbourhoods. Participants were asked how they observed changes in temperature, precipitation, and wind, and their responses are summarised in Table 5.1 below. The results are compared with recent climate data (2020) from the Meteorological Services department in Eswatini for triangulation purposes and verifications to ensure credibility of the data collected.

Table 5.1. Climate change (to adapt to) in Eswatini

Participants	Changes in Temperatures	Changes in Precipitation	Changes in Wind
A [Environmentalist - housing]	Extreme temperatures	Erratic rainfall, extreme rainfall events	Stronger winds
B [Meteorologist - Gov]	Extreme temperatures	Erratic rainfall, overall declining rainfall, extreme rainfall, long dry weather	
C [Environmental Health - Gov]	Increased temperatures	Erratic rainfall, extreme rainfall events	Increased wind pressure, change of wind patterns
D [City Planner - Municipality]	Increase in temperatures	Increased flooding events	High winds
E [Maintenance engineer - Municipality]	Extreme temperatures	Erratic rainfall, Extreme rainfall events, extreme storms	Strong winds
F [Environment and Public Health Specialist - Municipality]	Increased temperatures,	Drought - declining rainfall	Faster winds, drier winds
G [Disaster risk manager - NDMA]	Increased temperatures	Shifting rainfall season (time), Erratic rainfall, strong rainfall episodes, hail	Strong wind episodes,
H [Climate change consultant and academic]	Increased number of hot days, increased mean temperatures	Slight decreasing annual rainfall, erratic rainfall, huge rainfall episodes	Increased storm frequency
I [Public and environmental health specialist - town board]	Increased temperatures, extreme temperatures	Erratic rainfall	Unpredictable wind times
J [Disaster risk manager]	Extreme temperatures, dry spells		Strong winds, localised winds
K [Disaster risk manager]	Increased daily temperatures	Intense rainfall events	Increased wind speed, Unexpected winds

5.2.1. Temperature changes

The interviewed experts were questioned on observed temperature changes witnessed in their everyday work and it was observed that all participants shared the same understanding that average temperatures are generally increasing as they either responded by stating that temperatures are increasing or temperatures are becoming extreme, with one participant (H) clarifying that there is actually an increase in the number of hot days. Participants came to this conclusion based on their experience as professionals in climate analysis (meteorologist and climate change consultant), observed effects of temperatures (maintenance engineer and disaster risk managers), and general prolonged observations of weather, with some comparing their childhood experiences with what they experience at present.

Participant B, who is a meteorologist, monitors climate, prepares climate summaries, and further prepares climate reports for Eswatini, which creates confidence in the participant's response. Concerning temperatures he stated, "When it comes to temperatures, we see a slight increase… since we might have an increase in the number of heat waves, so we need to look at how our buildings will be retrofitted going forward." Participant H who is a climate change consultant and academic supported the views stating that "Temperatures are definitely rising. It shows in an analysis from 2010 that temperatures have risen by almost 1deg, and it keeps increasing." Other participants who have only observed temperatures from the work they do, confirm the same views (Table 5.1).

The Meteorological Services Department in Eswatini (2020) states that there is an observed increase in maximum temperatures which were observed over a period of 40 years, as presented in Figure 5.2 below.

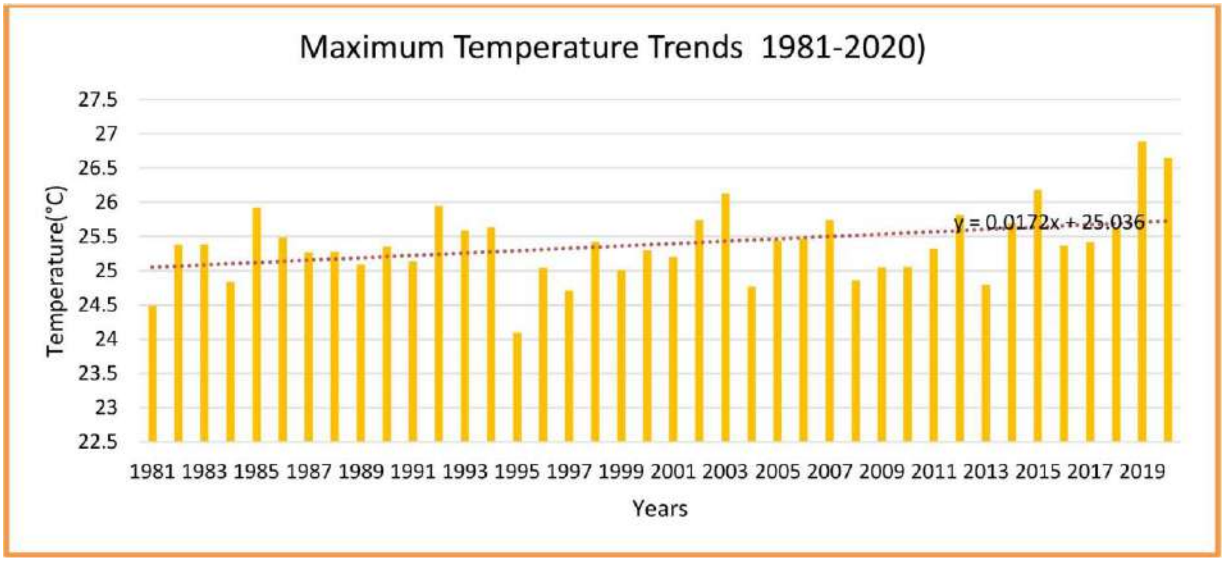


Figure 5.2. Temperature Trends (1981-2020) (EMS, 2020)

The 2011-2020 and 1981-1990 periods show a steep increase in maximum temperatures, with the last decade under review being the hottest. According to the Eswatini Meteorological Services (EMS) (2020), in 2019 and 2020 the country experienced the hottest days on record which confirms that temperatures are indeed increasing with time in Eswatini. The minimum temperatures have also been observed to be increasing in the analysis of the 40 years' data trend (Figure 5.3).

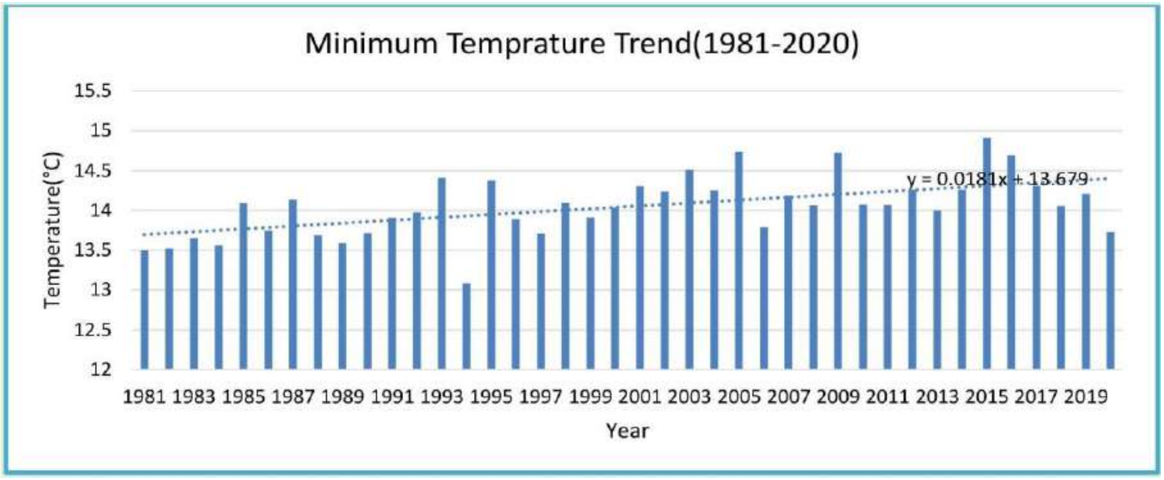


Figure 5.3. Minimum Temperature Trend (1981-2020) (EMS, 2020)

When the 40-year data trend was broken down into decades however, it was observed that the 2011 - 2020 decade showed a decline in minimum temperatures showing that average night time temperatures were becoming cooler. In this decade it means day temperatures were very high and night temperatures were very low.

In view of the confirmed temperature trends by the government, all participants accurately observed the temperature changes based on the effects they see on their everyday work. For instance, participant 5 (maintenance engineer) observed that roads are now frequently bleeding, which was not the case in the past, which according to the participant, meant that temperatures are now extreme (very hot). None of the participants speculated the rate of change but they were confident in their responses that temperatures are getting extreme with time, as evidenced by the MTEA's report.

5.2.2. Precipitation changes

Regarding precipitation, most participants responded by stating that rainfall is now erratic with extreme rainfall episodes. A few (participants B, F and H) further noted that there is an overall decline in rainfall and referred to examples of the recent drought in 2015. Participant H noted that the rainfall trends are misleading, stating that,

> "...although annual rainfall is not decreasing dramatically, the trend is generally downward, and that is true almost all over the world. But this is misleading because you might think that we are going to get the same rainfall. No! Cyclones are changing. You

might get the same overall rainfall, but you might get huge intense rainfall episodes. Rainfall you would get in months you find that you get in a week which is very bad for agriculture and infrastructure."

The participant emphasised the unpredictability of rainfall which cannot be understood properly through the trend diagrams, which may give a sense that rainfall is constant and even throughout the year.

A second common observation regards the erratic nature of rainfall, with most participants noting unpredictability in magnitude, period, and intensity. For example, Participant C suggested that rainfall season times have changed, stating that:

"...you may remember that rains used to start in August which we used to say is rain preparing soil for the ploughing season. Around September we would prepare or start planting. But this has all changed. Now if you plough before November, you run the risk of losing your crops, because the intensity of the sun in November and December might damage your crops."

The erratic nature of rainfall seems to be the main observation across most participants, noting unpredictability in magnitude, period, and intensity.

The Department of Meteorological Services in their analysis of rainfall in the 40-year period, noted that there is a general decline in the amount of average total annual rainfall in Eswatini, with the greatest decline being observed in the last 10 years (2011 - 2020) (Figure 5.4). This period was noted to have included the 2015 El-Niño episode which was claimed to be one of the driest years on record.

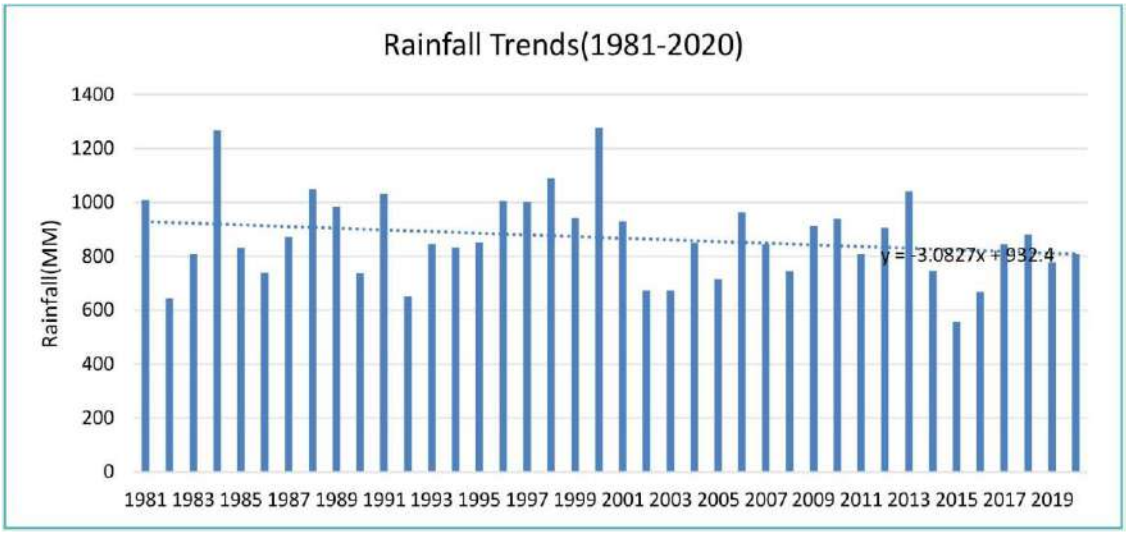


Figure 5.4. Rainfall Trends (1981 - 2020) (EMS, 2020)

Participant H, based on her experience as an analyst of climate data, however, did observe the false picture given by the trends which does not show the erratic nature of the rainfall. This can only be observed in monthly trends rather than annual trends of rainfall. The participants' observations therefore aligned with the MTEA's report on rainfall changes as well.

5.2.3. Wind changes

When it comes to wind changes, participants observed that winds are becoming stronger or faster, which suggests that the intensity of wind is increasing with time. It is noted that wind changes are not well enough observed, mainly since they come with the heavy rainfall events. However, participants still made similar observations. Participant A suggested: "I do not believe the (wind) patterns are changing, but instead they are becoming stronger and more extreme. The direction and path are still the same." Participant D also relayed thoughts based on reports on effects possibly caused by wind pressure, stating, "I think so (winds are changing), in certain parts of the country. We did have reports of houses falling and roofs flying off due to the high winds." Participant E also did not expand much on wind changes as the participant stated, "I can't say much about wind. Otherwise, winds *seem* to affect the low-lying areas, especially areas in the lowveld." Participant F, on the other hand, made some predictions based on scientific knowledge, stating that "winds *will* change because of the temperature. The warmer it is, it means the quicker the air moves up, and the quicker the cold air replaces the warm air."

The doubts and personal predictions concerning wind changes are clarified by participants B and H by stating that wind is not monitored in Eswatini, and it is not an everyday feeling you can easily observe. Participant B (meteorologist) responded by stating, "we have not been monitoring wind for a long time to be able to determine trends. But since we are already saying we are expecting an increase in high pressure storms, winds are going to be a factor going forward." Participant H (climate change consultant and academic) agreed that there is no study particularly for Eswatini on that (wind trends) but stated that in the African region we are expecting an increase in the frequency of storms, and they are linked with winds.

It is therefore concluded that based on the changes in temperature (increasing average temperatures) and extreme rainfall events, which comes with heavy and more intense storms, stronger wind is a factor worth considering as it is observed to be stronger as the storms intensify. As much as participants seem to lack concrete knowledge about the observed or expected changes on issues of wind changes, their observations of increase in intense rainfall events, which in most cases come with stronger storms, support the observations of the participants that indeed heavy winds are becoming more frequent and stronger with time. The major effects which are becoming more frequent as well, like blowing away of roofs and weak structures (as to be discussed in the next sections), also suggest that winds are becoming more intense and therefore more disastrous, and the country should consider monitoring wind as a matter of urgency to develop enough data to inform adaptable neighbourhood designs.

The following section discusses the effects of the changes in climate on neighbourhoods, as observed by the same participants involved in climate related issues or working on infrastructure and housing affected by changes in climate, with the aim to create a base from which to propose design solutions of adaptable neighbourhoods in later chapters.

5.3. Effects of climate change in Eswatini

Based on responses discussed in the previous section, all participants agreed that the climate is changing and reports by the Meteorological services confirm these observations with measured trends showing an increase in average temperatures, a slight decline in average rainfall, and an increase in intense rainfall events which come with strong winds. These changes have enormous effects on the neighbourhoods we live in, demanding these neighbourhoods to adapt to the changes in an attempt to curb the effects. Understanding how climate change affects our neighbourhoods will inform how these places should be planned to absorb or adapt to these effects, or else be flexible to be transformed by the pressures into better and flourishing places that will continue delivering the required services to residents.

To understand these effects therefore, participants were asked about the effects they observed as a result of the temperature, precipitation and wind changes they have observed. Their responses are summarised in Table 5.2 below and discussed in the following subsections.

Table 5.2. Effects of climate change on residential neighbourhoods (to which settlements need to adapt)

Participants	**Changes in Temperatures**	**Changes in Precipitation**	**Changes in Wind Patterns**
A	Reaction with material, Spread of diseases	Wash away houses, Food security/poverty	Blow away roof coverings
B	Overheating		
C	Spread of diseases, invading species, increased energy consumption, increased water consumption,	Flooding, which weakens structural stability and wash away bridges, damage to roads, soil failure (in the absence of rains or too much rainfall),	Disruption of services, destruction of houses, blown away roof coverings, wall cracks, wildfire

Participants	Changes in Temperatures	Changes in Precipitation	Changes in Wind Patterns
	decline in productivity, ecosystem changes	effects on materials, pollution of water, increased water demand	
D		Flooding of houses Landslides	Blown away roof coverings, falling houses, destruction in informal settlements, wildfire
E	Bleeding of roads, overheating of internal spaces	Destroying houses, drought, potholes, flooding of houses, more effects on informal settlements	Trees falling on roads and roofs, blown away roof coverings
F	Invasive species, spread of diseases, spread of malaria, sick building syndrome, heat stroke, compromised safety, socialising patterns, increase in energy consumption, inequality	Drought, flooding of houses, inaccessibility (slippery roads), infrastructure destruction (road failure), soil erosion, dredging, development of dongas (soil erosion),	Blown away roofs, removal of vegetation, forced use of non-ecofriendly materials, erosion of topsoil
G	Forced use of heat absorbing materials	Destruction of adobe houses, sinking houses, collapsing houses, collapsing walls, leaking metal roofs, moisture absorption by unpainted houses, cracking houses, water seeping through floors, falling walls and fences, soil failure beneath house, landslides	Destruction of roofs (especial weak metal sheets)
H	Air conditioning demand, increased internal greenhouse gases, inhabitable buildings, effects on human health, effects on agriculture, damage to materials (melting and cracking), urban health effects	Destroyed buildings, damaged gutters, flooding buildings, overflowing drainages, effects on roads, economic losses, drought, water scarcity	Blown roofs
I	Melting tar, increased energy demand	Drainage failure, flooding of neighbouring properties, soil erosion, invasive species, river pollution, increased renovation costs	Falling buildings
J	Dry spells	Flooding drainages, inaccessibility, damaged bridges, slippery roads, damage on roads, water saturation of mud walls, falling embankments	
K	Reaction with materials	Structural impacts on weak structures (such as stick and mud houses)	Falling houses, blown roofing

The effects relayed by participants were transcribed and further coded using sticky notes, as shown in Figure 5.5, and the sub themes which came up under the main themes of temperature, precipitation and wind, are discussed in the following sections.

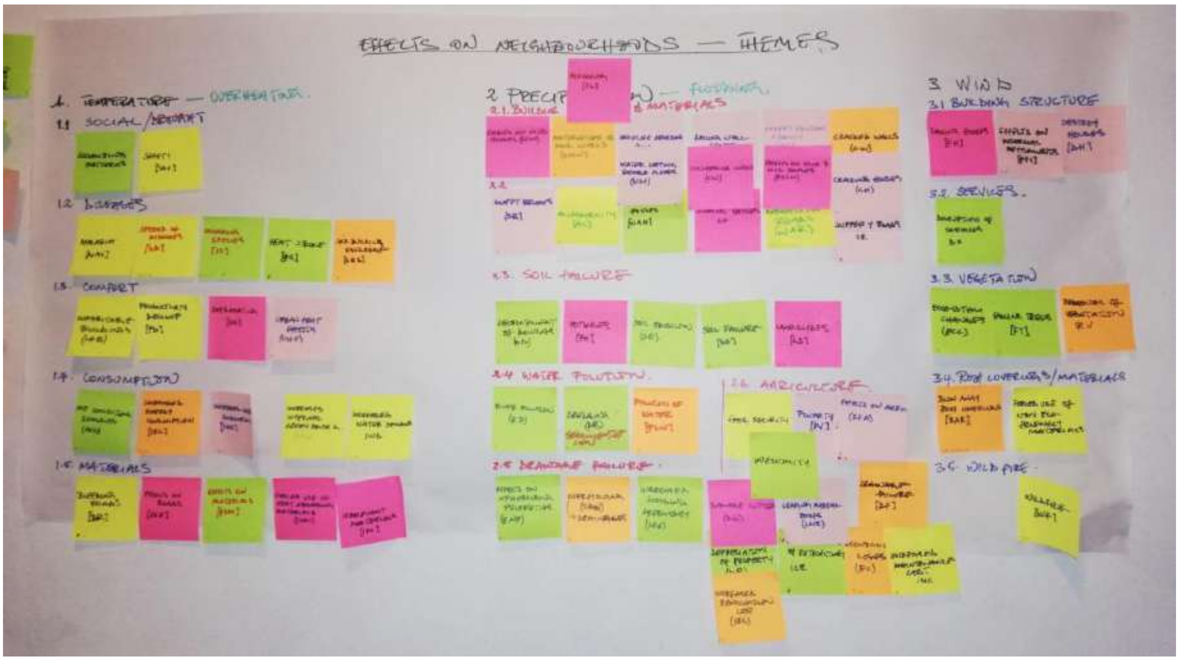


Figure 5.5. Coding of climate change effects

5.3.1. Temperature change disturbances

The changes in temperature (increasing or extreme temperatures and increasing number of hot days) are claimed to have major effects on residential neighbourhoods. Based on interview responses, five themes were created to group twenty-six identified and coded temperature change effects on residential neighbourhoods. All these effects are as a result of an overarching overheating effect. The themes identified were: Social effects, Human health effects, Human comfort effects, Building performance effects, and effects on Construction materials (Table 5.3).

Table 5.3. Effects of increased temperature on residential neighbourhoods

THEMES	Social effects	Human health effects	Human comfort effects	Building performance	Effects on construction materials
EFFECTS	- change in socialising patterns - compromised safety	- spread of diseases (malaria) - heat stroke and sick building syndrome	- uninhabitable buildings (unbearable heat) - productivity decline	- air conditioning demand - increased energy consumption - increased water consumption	- bleeding roads - forced use of heat absorbing materials - urban heat island

5.3.1.1. Social effects

Overheating is believed to affect socialising patterns due to unbearable heat conditions forcing residents to start spending more of their time indoors in the absence of trees providing shelter, and it affects the walkability of the neighbourhoods. In the case of unbearable outdoor heat conditions, it is a norm that residents would seek shelter against unbearable heat and dehydration. Respondent F states that

> "...climate change in residential neighbourhoods is basically changing the way people socialise. When it's too hot, no one wants to be outside. When it's too hot, if you do not have an air conditioner and my neighbour has an air conditioner, my neighbour will not leave the house."

In the absence of green spaces which give shade, people may find living indoors a better alternative if their houses are well built to control heat. This clearly shows that climate change influences personal mobility choices and may affect walkability and biking in a neighbourhood as a result of unbearable outdoor thermal conditions. Such effects would result in residents opting to use transport even for shorter distances, which further contributes to carbon emissions. Understanding movement patterns of residents in extreme heat conditions would allow practitioners to design walkable neighbourhoods which promote healthy living and improve outdoor thermal comfort.

The effect of extreme heat further affects socialising through external work as residents of a farming neighbourhood no longer work for long hours in fields on a hot day. It is a norm in the context of Eswatini that neighbours meet in fields to work together. This is a platform for casual discussion of social related issues which strengthens their relationship while they work. Extreme temperatures tend to rob residents of this opportunity, which will eventually not exist as agriculture is continuously being affected by heat. Participant H states that, "...if you are farming sugarcane, you need places with trees now where you can get refuge when it gets too hot." Participant C shares the same idea stating that, "People work in the early morning hours now (because of extreme heat) and break early."

Overheating resulting in external heat discomfort is therefore viewed as affecting socialising patterns established through collective working in agricultural fields and other outdoor activities, and walkability due to unbearable heat, with residents opting to use private transport rather than walking and biking. Most participants did not mention socialising effects directly, except for participant F, but this has come up from indirect comments from participants about external thermal discomfort causing people to seek shelter.

5.3.1.2. Human health effects

Higher temperatures further exacerbate the spread of diseases such as malaria which is common in very hot regions. Heat stroke and sick building syndrome have also been highlighted as effects of dwelling in overheated spaces. Participant F for instance, mentions,

> "In this regard, my first case will be the issue of malaria because we are now sleeping with open windows. And our windows do not have screens which can block out the mosquitoes... there can also be heat strokes you know. Nothing cools the house, so when there is no circulation of the air then what cools the house?"

Participant F has an experience in ensuring health and safety of residents in one of the big cities in Eswatini, and his responses were mainly concerned with the health of residents.

Malaria was highlighted by most participants as one of the main effects of higher temperatures. Participant A shared a personal experience and projections due to increasing temperatures, "...when I grew up, I used to know that Malaria spreads mainly in the lowveld, but due to the temperature changes they may make other areas like the Middleveld and Highveld to be more conducive to the spread of Malaria." Participant C, an environmentalist in the housing sector, shared the same views:

> "People have been exposed to diseases which they wouldn't have been exposed to if temperatures were not changing, since some diseases are driven by temperature conditions. For instance, the case of Malaria, known to be dominant in tropical climates or very hot areas, will eventually shift to other areas as temperature increases globally because mosquitoes will be breeding easily."

Based on participants' responses, overheating in the built environment as a result of extreme heat events is a serious concern for human health, especially for people exposed to the heat for a long period of time. Heat related health effects are experienced within indoor environments where occupants spend most of their time. External and indoor environments of neighbourhoods require, amongst other solutions, planning aiming to cool them and further prevent the spread of deadly insects such as mosquitoes.

5.3.1.3. Human comfort

Participants further raised concerns relating to human comfort. Participant C stated that "productivity also declines in the increase of temperature. In cooler weather, it's when productivity increases because people work more outside without being affected by the intensity of the heat." Based on this view, as extreme heat events increase, productivity will continue declining, which will eventually affect the local economy. This is in reference to external discomfort which may also result from the lack of vegetation and dried water reservoirs which cools outside air. Participants did highlight external discomfort, resulting in people doing external work for a short period to escape the extreme heat from the sun which may affect their health.

Overheated internal building spaces result in uninhabitable buildings, which reduces the health and productivity of occupants. The wrong use of building material is pointed as one reason for human discomfort as a result of overheating. Participant E for instance, stated, “Even in terms of building materials, if I may now comment, they use metal sheets as roofing so when temperatures escalate, it gets uncomfortable in the buildings. So if temperatures continue to increase, the internal spaces will be uninhabitable.” The participant clearly refers to the use of metal sheets without any insulation.

Human discomfort as a result of increased heat is observed indoors and outdoors which leaves no comfortable place where residents of a neighbourhood can escape to. Some participants responded by narrating how people are no longer managing to work outdoors while others responded by stating the difficulty in staying indoors, which all speaks to the same challenge of human discomfort which proposed neighbourhood designs should address.

5.3.1.4. Building performance

Participants have further highlighted impacts on building performance where buildings are now consuming more energy in an attempt to cool internal spaces, and consuming more water as occupants drink and bathe more often in hot days than in normal cool days.

Participant C shared his observations: “Nowadays we always consider installing air conditioners in our homes, yet these components consume a lot of energy.... When it's very hot you will bathe many times per day, for instance, to cool down.” Participant F agreed: “We grew up not having air conditioners but opening windows, nowadays all houses should have air conditioners and the windows must be closed and it's cool inside. You know what that is doing? It is increasing the consumption of electricity and now making electricity a demand...” Participant H also emphasised on the same issue of energy consumption: “So when you build without considering that there could be days where the temperature will be 9 degrees Celsius or 50 degrees Celsius etc., imagine the demand of air conditioning that will come as a result of that?” Participant I further highlighted that energy consumption is not only associated with cooling the building but warming the building as well. It is noted in the temperature trend that in the last decade, night temperatures are declining, which requires warming of the house at night. This means air conditioners work during the day to cool the houses and during the night to warm the houses. Participant I stated that: “Even on a hot day you need to have mechanical means of warming and cooling the buildings. The mechanical means are now required to assist the natural means".

Most participants have highlighted the effect of increased energy consumption as temperature increases (and decreases at night hours), with one highlighting water consumption demand with the increase in temperature which affects the building performance. The decline in rainfall and increase in water and energy consumption is of concern and requires creative means to address them, according to the participants.

5.3.1.5. Effects on materials

Among the effects observed due to the escalating average temperatures, are effects on construction materials commonly used in buildings and infrastructure without considering changes in temperature. Affected materials are, in most cases, those forming the outer shell (envelope) of a building, as they react directly with weather elements. These materials form a layer between occupants and weather elements and are therefore vital in controlling thermal comfort within the building. Infrastructure materials are also not spared from changes of climate as they react directly with weather elements.

Changes noted by participants had to do with undesirable reactions of material to extreme heat. Roads made of bitumen are claimed to be affected by extreme heat in an effect called bleeding, which causes the roads to be slippery. Participant E has raised this concern and clarified how the effect occurs on roads: "To add on issues of temperature, I can say that they are on their extremes and that affects our (road) surfacing which is asphalt. The bitumen below the asphalt tends to come above it which is called bleeding. It separates from the gravel and becomes slippery for vehicles." Participant I also mentioned the same effect: "We have seen tar melting when it's too hot. So now it talks of the material that you are now using. You cannot just use any material. It should accommodate that one day when it's too hot what do you do?" Participant A without expanding stated: "You will recall that materials are composed of chemicals, so they would react with extreme heat..." Participant H, based on her experience as a climate specialist, asked rhetorically: "And the materials that we use for building, are they good for that high temperature? Such high variations. Have we thought of that? Are we sure that the materials will last long? It will not crack, it will not melt? You know there can be all kinds of impacts."

The gradual increase in temperature is observed as having effects on materials which expand, melt, crack and lose their structural integrity. The correct materials selected based on local temperature and its changes should be selected to withstand the expected and unexpected impacts from overheating and direct rays from the sun.

Precipitation changes have also been observed to have impacts in our neighbourhoods, and findings from participants are discussed in the next section below.

5.3.2. Precipitation change disturbances

Precipitation has been observed as being unpredictable with intense rainfall events which leave behind a trail of destruction. Cyclones are becoming more frequent with major impacts on housing and infrastructure. Participants further highlighted the decline in rainfall where in some years a drought is declared, such as the 2015 drought in Eswatini and neighbouring countries. The meteorological services' reports align with the claims of participants concerning observed changes in rainfall.

The participants were asked to respond to questions on how the observed change in precipitation affects residential neighbourhoods. Responses were recorded, coded, and themes arose as discussed below. The themes derived were agricultural effects, building structural effects, infrastructural effects, and environmental effects (Table 5.4). Precipitation change effects are observed as the major effects experienced in Eswatini in comparison with the temperature and wind effects, considering the number of effects listed under each category. All participants had a lot to say about the effects of precipitation changes and had quoted a number of references.

Table 5.4. Precipitation effects on residential neighbourhoods

THEMES	**Agricultural effects**	**Building structural effects**	**Infrastructural effects**	**Environmental effects**
EFFECTS	- Food security - Poverty	- Moisture saturation in walls - Water seeping through floors - Collapsing building walls and retaining walls - Cracking walls	- Destruction of bridges and houses - Washed away roads - Slippery roads - Flooding of properties - Overflowing drainage - Damages to gutters - Leaking roofs	-Soil failure - Soil erosion and landslides - Increased potholes - River and water pollution - Sedimentation

5.3.2.1. Agriculture effects

One of the major fears of climate change, specifically changes in precipitation, is the effect on food security. The unpredictability of rainfall, combined sometimes with extreme storms, makes farming a challenge. In some instances, meteorologists may attempt to predict changes in rainfall for the year, only to experience a different weather pattern altogether.

Participants, when questioned about effects of rainfall, mentioned among others, soil failure due to the absence of rain. Effects on soil automatically affects farming on which Eswatini's economy is heavily reliant. Participant C, relying on experience acquired as an environmental health specialist, mentioned that: "Now in the absence of rain, soils known to hold water are affected, like cracking of clay soils. If you do agriculture in such land, your crops are definitely affected." Participant H discussed water scarcity which also affects agriculture among other effects. The participant fears that "with climate change, we will experience water scarcity…". Participant F shared the same observations: "We are now really facing drought. Farming is no longer practised in a lot of regions across the country. We are now facing water rationing…". This participant further made an example of the year 2015 when there was drought, mentioning that dams and streams were dry, and there was water rationing across all major towns in the country for almost the whole year.

Soil failure and absence of rain related to agriculture were the main concerns mentioned by participants, with fears of poverty being expected if the conditions remained unaddressed. It is of note that some participants were worried about the level of poverty in the country which is now worsening as a result of the unpredictable rains and disastrous heavy rainfall events.

5.3.2.2. Building structural effects

Other effects of changes in rainfall discussed by almost all participants, especially those involved in disaster management, are those relating to building structures. One of the major effects which is overarching most of the discussed effects in this section is flooding as a result of the unpredictable heavy rainfall events and cyclones which are becoming more frequent. Participant D, who is a town planner, related: "...we had to deal with issues of flooding, that's the big impact we had to deal with." Flooding has been observed to wash away houses, flood internal spaces of buildings, destroy stick and mud houses, and weaken structural stability, leading to walls developing cracks or collapsing, and cause failure of foundations beneath houses (houses on flood plains). Heavy rain further damages gutters and contributes to similar structural impacts. Participants expanded more on these effects, as restoring the destroyed neighbourhoods proved to be very expensive and impossible for some residents who could not afford repairs.

Participant C narrates how the structural stability of buildings is affected: "During heavy rains, the bearing capacity of structures is eroded… soil just normally fails when it's soaked with too much water such that some structures are destroyed, such as those made of stick and mud, wood and shacks." Participant E stated that when it comes to flooding, houses in upgrading areas are swiped away, or water enters the houses. This participant, among others, observed that the areas most affected by flooding are the upgrading areas. The neighbourhoods referred to as upgrading areas are the informal areas consisting mostly of adobe houses, which are currently being formalised (given tenure) since 2008. The structures built in these areas were self-built and were not controlled by the municipality as they were built informally. These areas are more vulnerable to disasters.

Participant G, who is a disaster risk manager who experiences these effects first hand, shared her experience about the effects of flooding:

> "It's bad I am telling you… this thing (cyclone) did not want any mud house…, a house built of stick and mud. I am not referring to the compressed mud bricks but those using soil without any compression. I am talking about the Hhohho region only where we had about 500 houses reported to have been destroyed… For houses which were found not to have a slab, the houses were sinking, the houses were collapsing. So, the house would either be sinking or collapsing. There will be walls collapsing, if it's not the walls it's the whole house…"

This participant further mentioned that the main challenge emanates from the rapid urbanisation as people would settle in flood plain areas. The participant further mentioned that it is difficult to assist people living in these areas as there are challenges concerning tenure.

The low-income neighbourhoods are clearly the most vulnerable to flooding according to submissions from most participants. The question is, how can these neighbourhoods be transformed to adapt to climate change in an attempt to minimise the identified discussed impacts?

5.3.2.3. Infrastructural effects

Effects of changes in precipitation were not only observed on buildings but also the infrastructure in the neighbourhoods. This category includes effects such as sweeping away of bridges, effects on roads like potholes and slippery roads, overflowing drains, flooding of neighbouring properties, and collapsing embarkments. Even in this category, flooding is viewed as the overarching effect causing all the other listed effects presented by participants.

The intense rainfall events which come with storms frequently result in flooding of neighbourhoods, and not only buildings are swept away, but also bridges and some components of roads. Participant C did mention this: “during heavy rains, the bearing capacity of structure is eroded. Roads are eroded, bridges are swept away by floods…” Participant E, as a maintenance engineer, stated that when there are long periods of rainfall then they know that the maintenance costs will be very high. Potholes will develop everywhere due to extreme rainfall. This participant further explained how the effects occur: “The roads are being destroyed. You find that the rainwater is diverted away from water drains and moves on the asphalt itself which is not meant to be a drain and that is causing problems for us. So definitely there are a lot of problems coming with the changes in rainfall.” The issue of flooding drains was also brought up by Participant J, stating: “Some of the towns we have, I will make an example of Nhlangano, we have a lot of drainage flooding which happens around here during the summer when there are heavy rains.”

On the other hand, Participant I further discussed that the storm water drains which are no longer handling the rainwater cause further problems to neighbouring peri-urban areas outside the town. The participant narrated,

> “I can share with you a bit of our experience here, where we had one road which was not draining properly…. if you do not have a proper drainage system here in town, the water flows to these peri urban areas. Right now, we are in talks with a community (A) where water… flows to be received by someone at the far end of this community, passing through peoples’ homes. This causes erosion which is extremely bad.”

5.3.2.4. Environmental effects

The absence of rain (drought) and flooding has been observed to have an effect on food security, therefore escalating poverty and inequality. This is exacerbated by existing cultural practices of land allocation. For instance, Participant A touched on flooding effects on agriculture by criticising farming land allocation in Eswatini which is determined by the community council which does not necessarily investigate the potential and condition of the allocated land. The participant stated: “On Swazi Nation Land you can be allocated a flood prone area for building and also farming, and this will indirectly affect our livelihoods and further escalate poverty levels.”

Participant F, on the other hand, talked about the absence of rain which affects farming: “Farming is no longer practised in a lot of regions across the country. We are now facing water rationing. Two to three years ago there was water rationing in Mbabane.” Drought affects vegetation which animals as well as human beings depend on for survival, which escalates poverty and food insecurity.

5.3.4. Wind change disturbances

The last set of questions to participants were about wind effects. Respondents observed winds as gaining more strength and becoming more frequent. Storms come with intense rainfall events which are also becoming more frequent. The winds are disastrous, according to participants. The effects, as given by the participants, were coded and three themes emerged. These being: structural effects, destruction of services, and environmental effects (Table 5.5). The effects are discussed below.

Table 5.5 Wind effects on residential neighbourhoods

THEMES	**Structural effects**	**Destruction of services**	**Environmental effects**
EFFECTS	- Falling houses - Blown away roof coverings - Forced use of non-eco-friendly materials	- Disruption of services	- Falling trees - Ecosystem changes - Wildfire

5.3.4.1. Structural effects

Increasingly intense storms with high winds affect properties mostly by blowing away roof coverings or the whole roof system, leaving cracks on walls, and even going to the extent of completely destroying houses with low structural integrity, like some informal houses built of sticks and mud. These effects have also been noted by most participants to be affecting the informal settlements, some of which are being formalised. Most participants noted that these effects particularly affected informal and formalising settlements. Wind effects have also been observed the most in the lowveld, an area at a lower altitude compared to all the other geographical regions of the country.

One key wind effect noted by most is the effect on roofs. The effect on roofs is a key impact of strong winds noted by most participants. Participant A, in the housing sector, brought up the example of their own housing where they had to replace the roof structure almost every year in the recent years, until they had to build parapet walls to shield the roof structure from exposure to winds. When Participant A was asked about the frequency of the winds recently, this was the response: "...very often until we changed the roofing by building parapet walls to hide the roof sheets. Otherwise, it was almost certain that between September and November, Mobeni roofs would be blown away." Mobeni is a residential neighbourhood developed by the Eswatini National Housing Board. Participant D shared the same observations concerning wind effects: "we did have reports of houses falling and roofs flying off due to the high winds…" It was only two participants (B and J) who did not raise the issue of roof covers being blown away as there were no clear responses given concerning effects of winds on roofs.

Participant C highlighted the destruction of houses beyond repair without being specific on how the structures are destroyed. The participant stated: "Buildings are destroyed, and people are forced to rebuild their houses… some people would have to relocate to stay in places of safety." Participant I clarified that the houses which were destroyed were those with poor structural integrity: "It does (change of wind affect residential neighbourhoods), if your building has a compromised structural integrity on a windy day it will fall". Participant K, who is an experienced disaster manager, confirmed from experience that some houses even collapse. He stated that some of the winds are just too strong for some of the houses. This participant further implied that the strength of the wind even tested the integrity of the structures they built for affected communities, which were previously deemed strong. The participant stated as follows: "You would find that the same house we had built for someone has been blown away again the following year, and then we changed it and went for some consultants in 2016. They gave us a new plan which is a little bit climate smart." This organisation acknowledges the need for a design which is climate smart.

5.3.4.2. Destruction of infrastructure

Wind effects were not only observed to be negatively affecting buildings but also infrastructure. Participants observed strong winds to be disrupting services, more especially electricity, which after the storms may take several days to be reconnected as power lines are damaged. Roads are also damaged as a result of big trees falling on roads, according to some participants. Participant C highlighted the issue of disruption of services stating: "first of all it (heavy wind) disrupts services with trees falling on roads and destroying infrastructure." Participant E, the maintenance engineer, also referred to the issue of road damage: "Infrastructure is affected. When winds blow down trees, the roads are normally damaged and that affects us in a way." The effects on access also affect the response time to the affected neighbourhood. Participant E further suggested that there is a need to limit the height of trees planted or that are growing along the roads. It is the role of this participant to ensure proper maintenance of the roads. Such a comment does show that there are some constraints in executing this task of cutting trees, and this might be a new concern with the winds slowly gaining strength with time.

5.3.4.3. Environmental effects

There are several environmental effects which were noted by participants. The uprooting of trees, as discussed above, is one of them. It shows that there is an effect on vegetation, especially trees which break branches and become a hazard to residents and further disrupt services. Wildfire is also one major concern when it comes to the frequent winds. Wildfire burns up vegetation and further puts residents in danger of damage to their property. It is Participant C who noted the effects of wildfire stating that: "when it's windy, wildfire easily spreads and can affect residential neighbourhoods." Participant D seems to also have observed this in his role as an environmental and public safety specialist, as he stated: "With wind patterns we have issues of wildfires. The speed of wildfires is normally caused by wind. So, there is also that. We have homes burning down, and people are not mitigating. People don't have insurance for housing, and they lose things because of that."

5.4. Discussion

The analysis suggests that climate in the context of Eswatini is changing. Temperature, precipitation and winds are all changing with time. Temperatures are getting more extreme, and there is an increase in the number of hot days. The extreme temperatures result in very strong rainfall events which are accompanied by storms. Such events are evidenced by the frequent cyclones which leave a trail of destruction particularly in the southern region of the country. These frequent events do not mean rainfall collected is increasing, rather it is slightly declining as evident in the 40-year trend discussed in the earlier sections. In 2015, Eswatini experienced a severe drought, especially in the southern region, which forced the Water Services Corporation in Eswatini to ration water supply. Agriculture was affected and poverty levels increased. Rainfall is deemed unpredictable as in some years after the drought sufficient rain was collected but the extreme rainfall events persisted. These events come with storms which carry disastrous winds because of their intensity and unpredictability. It is of note that the changes in temperature, precipitation and wind cannot be separated as one is influenced by the other. Temperature changes force precipitation, as well as the intensity of winds to change.

These changes, as discovered in the findings, have been confirmed through comparisons with a recent climate change report (EMS, 2020) produced by the meteorological services department under the Ministry of Tourism and Environmental Affairs in Eswatini. The trends in temperature do show increasing average maximum and minimum temperatures, with a decline in average minimum temperatures over the last decade. The rainfall trend in the report does show an overall slight decline in rainfall and unpredictability as some years had rain but some had none. Wind is not studied, but the increase in strong rainfall events with heavy storms is evident enough to indicate a change in wind as well.

Kunene, Mthombeni and Antwi (2019) confirm that there is growing evidence that extreme events such as droughts and floods have now become common occurrences in sub-Saharan countries, as was observed by the participants. The Eswatini National Climate Change Strategy Plan (2016) states that in line with these trends, including the consistent warming trend, the country needs to adapt to the changing conditions. The accuracy in response proves that participants understand climate change and the expectation is that the effects of these changes are also well understood. With climate change having been established in the context of Eswatini, developments specifically adapting to these changes have to be initiated. The study has further identified the effects to consider in preparing adaptive responses.

The effects of these extreme and unpredictable climate changes are generally resulting from flooding, overheating and extreme storm events. These events, according to the analysis, collectively affect building structure, infrastructure, environment, and the social life of residents. For instance, extreme rainfall events affect buildings by seeping through the building envelope of some buildings, affect infrastructure by swiping away bridges, affect the environment by polluting streams, and indirectly affect social life by destroying produce hence poverty. Increased temperature affects buildings as well through increased energy and water consumption, affects infrastructure by changing material conditions such as road surfacing, affects the environment through the rise of invasive species and diseases, and affects social life by the spread of diseases and thermal discomfort. The identified effects from temperature, rainfall and wind changes can therefore be consolidated using the dimensions affected by overall changes in climate as depicted.

5.4.1. Social disturbances

Overheating was considered to affect the health and wellbeing of occupants. Malaria is one disease brought up, as it is known to spread more in hot and wet climates. Heat stroke and sick building syndrome are believed to affect building occupants as a result of excess heat. According to Lomas and Porritt (2017), these health issues resulting from excess heat can lead to premature mortality, more especially amongst the vulnerable members of the affected communities such as the elderly. The elderly are more sensitive to ambient conditions, as with age one physiologically becomes less able to regulate one's body temperature, which can be worsened by medication, which according to Lomas and Porritt (2017), further reduces physiological tolerance. This, as well as other factors, means that the elderly, especially those living in unfavourable building conditions, are more at risk during hot weather spells.

Extreme heat, along with the absence of rain, has been observed as affecting agriculture which in fact exacerbates poverty. The 2015 vulnerability assessment and analysis report estimated the number of food insecure people in Eswatini as 200,897, as a result of the severe El Nino-induced drought of 2015, and by the time of compiling the report, this number was expected to rise to about 300,000, which is about 30% of the total population of Eswatini (NDMA, 2015). This was caused by the conditions which were not favourable for planting crops. It was observed in the report that there was a significant reduction in the area planted with crops in that season, as well as deteriorating pasture conditions which led to 38,000 cattle dying as a result of the drought. As predicted by the participants, such conditions will become a norm with the rising temperatures, decline in rainfall, and more frequent disastrous winds.

The current building regulations of Eswatini do highlight the requirements for adequate ventilation and design of windows to ensure adequate natural light. However, there is no mention of designs to control overheating in warm climates. While the issue of overheating is well accepted by experts, as noted in the responses by participants, the matter is still paid little attention in practice. It is a norm that the construction industry focuses on reducing costs and increasing the speed of construction, giving rise to lighter precast material which may not be sufficient in ensuring internal building comfort. Residents may be resistant to the change of building aesthetics to incorporate shading devices on facades, wind breaks, green roofs, or any other climate controlling devices which may further escalate costs.

Further to the above, walkability of neighbourhoods is one major effect relating to the social dimension. Extreme heat is seen to be affecting external thermal comfort which may prevent residents from walking, exercising and meeting in public areas. Such limitations may result in a population which is not physically or even emotionally healthy. Further possible impacts include inefficient land use, increased travelling costs (and carbon emissions), decline in local economy, and a possible drop in liveability.

Participants mentioned walls absorbing water and even cracking due to flooding, yet they did not mention the health effects which come with dampness. Bruce et al. (2003) highlighted the possibility of human illnesses which relate to indoor mould growth in buildings. Dampness in a house accumulates on edges, cracks, and other parts of the house which promote the growth of mould. Adedeju and Salami (2011) mention that flooding can create conditions which promote secondary threats of waterborne, as well as vector borne, diseases.

It can be concluded that overheating resulting from extreme temperatures and flooding experienced as a result of extreme unexpected rainfall events, result in social related disturbances in neighbourhoods which require urgent attention.

5.4.2. Environmental disturbances

Neighbourhoods have an environmental dimension, which is important for the provision of ecosystem services to ensure survival of the residents. Extreme weather conditions experienced in the twenty-first century have been proven to have an impact on the functioning of the biosphere. These effects on nature destroy its ability to provide the resources on which humanity depends for its survival (Robinson & Cole, 2015:136).

Environmental stress can worsen poverty as it has implications for global food production, and also threatens biodiversity (Raworth, 2012; Mang & Haggard, 2016). It is vital for dwellers of residential neighbourhoods to appreciate and have access to ecosystem services, such as those listed by Diaz, Fargione, Chapin, and Tilman (2006) as: “shelter, fresh water, food, biomass production, nutrient cycling, and water cycling”.

The environmental effects caused by climate change identified in the context of Eswatini have also been seen to have an effect on food security and therefore poverty, shelter, and freshwater, among other effects. Food security is mainly affected by soil failure, water scarcity, and extreme heat which span over long periods of time. Soil erosion and landslides as a result of flooding further disturb arable land as well as the integrity of the soil. Water is polluted by flooding and winds escalate the frequency of wildfire. All these effects on the environment are also a risk to the survival of human life in Eswatini. Poverty is one major effect which results from the listed environmental disturbances.

There is, therefore, an increased concern regarding climate change risks to urban ecosystems and the urban poor (IPCC, 2014). Smith, Maes, Stojanovic, and Ballinger (2011) state that governments and organizations are battling with addressing the effects of climate change with the aim to improve the resilience of communities and ecosystems. New ways of designing our neighbourhoods to adapt to environmental effects should be devised as a matter of urgency to reduce the rate of poverty, amongst other challenges.

5.4.3. Infrastructure disturbances

Infrastructure is designed based on tested standards so that it can withstand local conditions which are now changing. However, participants have observed infrastructure to be affected by the climate in recent years, which means infrastructure no longer withstands current climate conditions, as some participants mentioned. Climate change shifts climate characteristics, causing infrastructure to be exposed to new unknown risks which have not been considered previously. This implies that infrastructure in the country is not resilient to climate change. A resilient component of the neighbourhood should be able to absorb even the unexpected disturbances and bounce back or be replaceable.

In strong storm events, it is almost certain that infrastructure will fail, and its design should be reconsidered. For example, electrical poles for transmission of power are affected by strong wind. Underground electrical cabling may prove to be costly, but this might be the time for such or similar solutions to restore power provision even during storms (engineering resilience). However, currently in Eswatini only a handful of townships opted to use underground cables and this system is still not well supported by the Eswatini Electricity Company. Companies which provide such services need to find working and resilient solutions to limit infrastructure failure.

Flooding, on the other hand, sweeps away bridges and destroys roads, which affects accessibility. This suggests that the lack of alternative routes and connectivity in the design of the road network means that the failure of a bridge or road disrupts movement and hence the proper functioning of that community. Providing emergency aid to affected areas may prove difficult in such instances, which may even lead to increased mortality as a result of flooding.

Overheating melts the surfacing of tarred roads with the maintenance engineer who was a participant admitting that the road designs need to change. Off-the-shelf designs, which some participants called a ‘blanket approach’, are no longer relevant, but each area should have a unique solution which works with the climate of that area and expected future changes. This also speaks of regulations and policies which require to be changed to guide practitioners to a new way of design. Procurement processes also may need to provide the right guidance to tendering companies to guide the design of roads and other infrastructure.

5.4.4. Building disturbances

The building dimension is another critically affected dimension which requires serious attention according to the participants. The effects identified suggest that these buildings were designed without considering future climate data. It is noted however, that even though the design of a building would play a major role in resisting climate disturbances, good operation of the building such as opening windows at the right time, has an equal contribution to ensuring a building is resilient to climate change impacts. Several climate change disturbances to buildings result from flooding, overheating, and frequent storms.

Floodwater, according to participants, pose several threats to buildings, with the depth of water affecting foundations and therefore the stability of buildings. Buildings with weak structures such as those located in upgrading areas tend to be more vulnerable compared to houses in other urban zones. Water seeps into the buildings through cracks and gaps and is further absorbed by walls, creating breeding grounds for mould which affect the health of residents. Buildings soaked in water further have their building materials reacting with moisture, which weakens the rigidity and strength of the materials, reducing its lifespan.

Effects of changes in temperature in buildings have mainly been pointed to be on performance of the buildings, an area widely explored in academic research. The unbearable internal temperatures are mostly as a result of poor ventilation, selection of materials with high U-values, operation of the building, as well as the orientation of the buildings. These are some areas identified that require urgent attention to address issues of thermal comfort in buildings.

Wind effects on buildings on the other hand are observed to be testing the structural integrity and connection of the building envelope to the structural system, as participants observed structures falling, or roof material being blown away as a result of excess wind pressure.

Buildings therefore need to adapt to flooding (rising water levels, high velocity of water flow), overheating, and wind pressure, among other disturbances which cause collapse of buildings, dampness of materials, and erosion of soils and buildings. The climate change effects to which residential neighbourhoods need to adapt and risks to the neighbourhoods are summarised in Table 5.6 below.

Table 5.6. Climate change risks in residential settlements

Area of climate change impact	**Risks**
Infrastructure Impacts	Destruction of bridges
	Bleeding of road surfaces
	Slippery/washed away roads, potholes
	Disruption of services
	Overflowing of drainages
	Urban heat island

Area of climate change impact	Risks
Building Impacts	Mould accumulation/ moisture saturation
	Weakening of building structure/ cracking and collapsing walls/ blown away roof coverings
	Sinking houses
	Increased water consumption
	Increased energy consumption
Environmental impacts	Food production/ agriculture
	Soil failure/erosion/landslides
	Water/land/air pollution
	Wildfire
	Ecosystem changes
	Sedimentation
	Falling trees
Social impacts	Spread of diseases
	Heat stroke and sick building syndrome
	Effects on socialising patterns
	Crime
	Productivity decline

5.5. Conclusion

The growing realisation that climate change cannot be avoided calls for the exploration of climate change disturbances to which our neighbourhoods should adapt in order to ensure continuous functioning of the neighbourhoods. This chapter aimed to present findings to respond to the first research question which sought to identify climate change disturbances to which residential neighbourhoods in the Eswatini context should adapt in order to thrive. What preceded this identification was to seek understanding of the climate change in Eswatini to link climate change to its observed effects through a desktop study. This allowed for the evaluation of participants' understanding of Eswatini climate change to ensure validity of the responses.

Experts identified through snowball sampling were interviewed concerning their observations regarding climate change in Eswatini and effects of such changes on the neighbourhoods we live in. In summary, it can be concluded that temperatures are increasing, as is the case globally. There is an increased number of hot days with night temperatures showing a drop in the last decade. Rainfall on the other hand is slightly declining with an increased frequency of extreme, disastrous rainfall events which come with storms and high intensity winds, especially in low lying areas. These events are unpredictable, which makes them hit when least expected. These changes have huge impacts on neighbourhoods in the context.

The disturbances as identified through interviews are organised according to the dimension of the neighbourhood which is affected identified as:

a. Disturbances to social life of residents
b. Disturbances to the environment (including agriculture)
c. Disturbances to infrastructure in the neighbourhood
d. Disturbances to buildings where residents live and work.

Disturbances to social life refers to the kind of disturbances which affect the well-being of residents as a result of changes in climate. These include health and comfort related disturbances resulting from overheating, pollution, and mould as a result of flooding. Disturbances to the environment come as a result of soil failure, erosion, drought, and invasive species, among other effects. Such disturbances affect ecosystem services, food security, and further affect waste disposal. Infrastructure disturbances entails effects resulting mostly from high pressure winds and flooding which erodes bridges and affects roads and power lines. Infrastructure disturbances have an impact on clean water supply, uninterrupted energy supply, communication, and movement and health of residents. Building disturbances refers to effects that test the structural integrity of the building as a result of extreme heat impacting the performance of buildings, high velocity water flow washing away buildings, and strong winds blowing away roof coverings, among other effects. These effects disturb the wellbeing and comfort of residents, safety of the residents using the structures, affordability, clean water supply, and uninterrupted energy supply.

All the effects experienced as a result of changes in climate in Eswatini seem to emanate mainly from flooding as a result of extreme rainfall events, overheating as a result of increasing average temperatures, and intense winds normally accompanying the frequent rainfall and hailstorm events. These effects hit upgrading areas the most and exacerbate poverty, hence, the focus of the study on upgrading/informal settlements. The experienced effects imply that the neighbourhoods are not resilient, as their function is affected by climate change. Neighbourhoods, especially those occupied by the urban poor, therefore require proper designs as well as proper operation to improve their resilience and ensure continuous function to meet set sustainability goals. Prior to devising resilience strategies that can be implemented, it is critical to assess the resilience of the area of concern to identify areas that require to improve or enhance their resilience. The following chapter presents results concerning a resilience assessment of a selected informal settlement.

Chapter 6: Resilience Assessment of Informal Settlements in Eswatini

6.1. Introduction

Climate change holds potentially serious consequences for low-cost residential neighbourhoods (Satterthwaite et al., 2020). This implies a need to determine how these areas can be managed so that they are able to withstand and adjust to climate change. In order to devise adaptation strategies of these areas, it is critical firstly to assess them in order to identify potential thresholds which represent a breaking point between two alternative system states and reveal what contributes to and what erodes the resilience of these settlements. For this, the study used the Resilience Assessment Framework (RAF) developed by the Resilience Alliance (2010) and described in Figure 6.1. This Framework was selected because it is based on ecological resilience theory and the concept of social-ecological systems (SES) in which human and ecological systems are considered one integrated system. This allows for a more holistic understanding of the urban system being assessed. It further provides a clear assessment process, not just a set of indicators, such as the City Resilience Framework (Rockefeller Foundation & Arup, 2014).

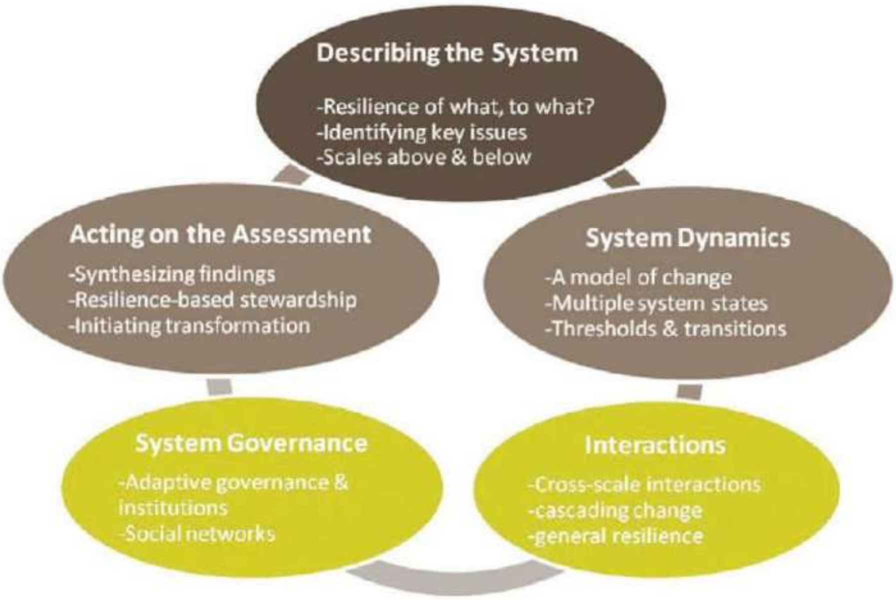


Figure 6.1. Resilience Assessment Framework (Resilience Alliance, 2010)

The assessment framework has five main stages with the first stage describing the system, the second stage understanding the system dynamics, the third stage probing system interactions, then evaluating governance for the fourth stage, and finally acting on the assessment. According to the Resilience Alliance, the process is iterative and reflexive at each stage and requires referring to earlier steps to make adjustments where required..

In this chapter and the following chapters, the assessment framework is used as an overarching guide to assess a purposely selected informal settlement to meet the second sub-objective of the study: *to assess the current adaptive capacity of informal settlements in Eswatini to climate change*. The framework was adapted to this study by selecting questions that are relevant to the study. The questions were interpreted in a checklist schedule (Appendix B) which was used to collect structured data through the use of the Epicollect5 tool (https://five.epicollect.net/). One key advantage of the RAF as an assessment tool is its flexibility, considering each assessment as unique and not all questions as applicable in all cases. Each section of the assessment employs a relevant methodology.

The following section describes the study area and how this selected area has changed over time for a better understanding of the dynamics of this system. The results of the resilience assessment conducted in the study area are then presented and discussed to determine the adaptive capacity of the Msunduza study area. The chapter concludes with a summary of the condition of the settlement, based on the findings and understanding of the system dynamics.

6.2. Describing the system

The first step in the assessment entails defining the socio-ecological boundaries of the focal system. The boundaries can be spatial and temporal (period). The very first step in defining the boundaries is the identification of issues of concern, which in this study also align with the main problem of the study. Once the issue(s) of concern has been identified, key components of the SES relevant to the main issue of concern are identified. This may require diversity of perspectives, according to the Resilience Alliance (2010). Thirdly, the disturbances which present challenges to the management of the SES are identified. In this study, the fourth step was to define the spatial scale by presenting the study area of focus. Lastly, the nested systems to which the focal system is connected, which function in multiple space and time scales, were identified. This study went through the five steps to clearly describe the system. The following subsections discuss each of those steps.

6.2.1. Main Issues of Concern

The main issue of concern is the vulnerability of informal settlements in Eswatini to climate change effects. Informal settlements provide affordable housing and access to essential services at low cost to the urban population. These areas further have environmental sustainability traces and potential which urban areas can learn from to develop environmentally sustainable settlements (Ndlangamandla & Combrinck, 2020). These settlements should therefore be sustained by increasing their adaptive capacity so that they thrive and continue to serve the urban population.

The interview with different experts on issues of climate change unpacked the main issue of concern for this assessment. The results of the interview are presented in Chapter 5 of this dissertation where risks of climate change on residential neighbourhoods of Eswatini are discussed. The impacts of climate change were claimed to be more severe in upgrading areas hence the claim that these areas are vulnerable to climate change and should be assessed and addressed urgently. This section stems from the detailed issues identified by the interviewed experts which are also the risks of climate change summarised as environmental impacts, infrastructure impacts, and building impacts as presented in Table 5.6 in the previous chapter.

The resilience assessment tool was used to evaluate the resilience of the selected settlement in Eswatini to the environmental effects, infrastructure and building effects resulting from climate change. These effects are specifically caused by extreme heat, intense rainfall or flooding, drought, and storms among other climatic changes as confirmed by the experts. The climate change effects, discussed in detail in Chapter 5, affect the valued attributes causing the settlement to malfunction. The results from the previous chapter revealed the valued attributes of residential settlements which need to be maintained to keep the settlements delivering the required services. The valued attributes in this context can be considered as the components which participants are concerned about which are affected by climate change. For instance, the participants highlighted that climate change triggers the spread of diseases. In this case a valued attribute is considered as health and wellbeing of the residents. Table 6.1 below presents the issues of concern for this study, and the valued attributes.

Table 6.1. Areas of concern and valued attributes

Areas of concern	**Valued attributes**
Infrastructure	Clean water
	Energy
	Communication
	Movement
	Wellbeing [health]
Building	Comfort and wellbeing
	Safety
	Affordability
	Clean water
	Energy
Environmental	Ecosystem services and Biodiversity
	Food
	Waste disposal

Adaptive capacity should be built in these settlements to ensure the settlement functions properly and transforms to be better than before. The study was therefore conducted to determine strategies of addressing the issues. The study used past information received through interviews as presented in the previous chapter and used current information or condition of the settlement determined through an observational study of the settlement.

6.2.2. Resilience of What, to What?

After establishing the issues of concern through interviews, the next step was to identify the SES components relevant to the main issues. These are the components which should be particularly assessed, and which should adapt to the climatic changes for the settlement to be considered resilient. These components were also determined through matching the valued attributes with settlement components that have a potential of maintaining that attribute or function. For instance, uninterrupted power supply is valued, and it can be maintained by ensuring the resilience of power supply systems. The components or subsystems which need to be resilient in an informal settlement are shown in Table 6.2.

Table 6.2. Components relevant to the valued attributes

Areas of concern	Valued attributes	Component
Infrastructure	Clean water	Water management systems
	Energy	Energy management systems
	Communication	Communication systems
	Movement	Roads and footpaths
	Wellbeing [health]	Heat management systems
Building	Comfort and wellbeing	Heat management systems
		Water management systems
	Safety	Wind management systems
	Affordability	Material
	Clean water	Water supply systems
	Energy	Energy supply systems
Environment	Ecosystem services and Biodiversity	Green networks
	Food	Food systems
	Waste disposal	Waste management systems

Informal settlements experience different disturbances, however, this study only focuses on climate change disturbances. The term 'disturbance' refers to anything which causes a disruption in a system, and the disturbances confirmed (through the interviews) to be affecting residential neighbourhoods in Eswatini are also listed in Table 6.2. They include flooding, which is mostly a pulse disturbance as it occurs as a relatively discrete event in time. Flooding affects buildings, infrastructure, and resources. Another disturbance, which is more of a press disturbance, is extreme heat. A press disturbance is one that is gradual or adds accumulative pressure to the system (Resilience Alliance, 2010). Lastly, storms also disturb the SES and affect the buildings, infrastructure and resources. Storms can also be classified as pulse disturbances as they come unexpectedly. The system should have capacity to deal with both the pulse and press disturbances (Resilience Alliance, 2010).

It is also critical to note that all these disturbances originate from processes occurring at larger scales, but they cause massive disruptions at settlement scales as discussed in the previous chapter. The frequency of flooding and storms or hurricanes is increasing with time and lasts either for a few minutes or hours but leaves a trail of destruction that takes years to restore. Their severity also increases with time and can be predicted to some extent by observing the weather patterns. This may make it possible to introduce warning systems to reduce their impacts.

The informal settlement components presented in Table 6.2 therefore need to be resilient to infrastructure impacts, building impacts, and environmental impacts caused by flooding, extreme heat (and drought), and storms.

6.2.3. Spatial scale of the focal system

In describing the system, the spatial scale is also considered. Msunduza, an informal settlement located in Mbabane, in the Hhohho region, Eswatini (Figure 4.2), forms the exploration ground for this study. This settlement is described in detail in Chapter 4 of this dissertation report.

As an informal settlement undergoing rapid urbanisation along with increased pressure from climate change, Msunduza provides several extreme urban design and planning challenges. These challenges which relate to resilience as well as sustainability, vary in scales. It is believed that the understanding of dynamics and structure of this neighbourhood through resilience thinking concepts, provides ideas for designing and planning a neighbourhood, as well as a city which responds to the changes resulting from the pressures of urbanisation and climate change in a manner which improves the resilience and sustainability of the urban system. In order to understand the focal system, which is the Msunduza settlement, it is vital to understand the scales above the focal system which have influenced its formation and the dynamics within the system.

6.2.4. Expanding the System - Multiple Scales and Time Scales

The focal system, Msunduza, is connected in various ways to several nested systems functioning at multiple space and time scales. This means that what happens at larger spatial scales, affects the focal system, and what happens at smaller systems nested within the focal system, also affects the focal system. A broader overview of the system changes through time gave an understanding of past disturbances and responses, and what was behind those changes (change drivers). This was critical in understanding how Msunduza got to its current condition, and what might affect future changes to this system. A historical narrative of the formation and development of Msunduza is given in the following paragraphs. The establishment and development of Msunduza was mainly shaped by the political and economic systems at larger scales. It is critical to understand how these larger systems shaped this informal settlement. This history is adapted from a report titled, 'A Brief History of Urban Development and Upgrading in Swaziland', written by Lowsby and De Groot (2007) and verified by the Ministry of Economic Planning and Development (Government of Eswatini) in 2007. The following paragraphs re-tell relevant parts of the history which affected the dynamics of the study area.

The city of Mbabane where Msunduza is located, had its origin setup and inhabited by settlers in 1888, almost the same time Manzini town was occupied (1885), and both settlements started as a trading store with a hotel. The existence of river water supplies within these towns and their location along train routes contributed to their success and sustainability. At this time, Eswatini was the protectorate of the South African Republic, however after the Anglo-Boer war in 1902, Britain took over the administration of the country and in 1907, Eswatini became a British protectorate officially. The country was governed by a High Commissioner in Pretoria and administered by a resident commission staff in Mbabane. Mbabane was chosen because of its proximity to the South African border and because of its climate which was preferred by the British.

The British were quick to apportion and expropriate land by dividing it into three: one third Swazi nation land (SNL), one third (British) crown land and one third freehold title deed, known as farm. The Swazis were deprived of land they had occupied for centuries as they had no right to live on Crown land or title deed land, so they were given 5 years to vacate. The allocated land to ordinary citizens became insufficient because of the growing population until the British government purchased back land for Swazis in 1940 which was given to Swazi authorities to allocate in the traditional manner. The size of the SNL increased to about 60 percent. By this time, economic development was slow except for limited mining activities. The whole country was mainly rural where farming such as cattle ranching was practised.

The end of World War II in 1945 came with several changes in governance, economy and housing. The change of government in Britain after the war changed hearts towards investments in the colonies. After the war, therefore there was a major increase in economic activities mainly through the Colonial Development Company and several British industries and because of the development of roads. The towns grew and Swazis occupied areas around the towns using annually renewed Temporary Residence Permits. These permits allowed them to build temporary shelters in selected areas. Swazis had no right to live in towns; however, after some time the temporary shelters built somehow became permanent homes of the dwellers and that eventually led to the formation of informal settlements such as Msunduza, claimed to be the first informal settlement that was formed in Eswatini.

After Eswatini gained its independence on 6 September 1968, there was a radical political change and a dramatic socio-economic change mainly along the Mbabane - Manzini corridor. There was an influx of shops and businesses transforming the cities into lively bustling centres. According to MHUD (2007) the main contributing factor to the rapid growth was that the independence coincided with trade and economic sanctions against South Africa at that time. South Africa and foreign companies found it beneficial to set up manufacturing or trading corporations in Eswatini to import or export goods and services into or out of South Africa.

This growth of Mbabane and other cities as well as increased government services escalated the demand for labour, so rural dwellers moved to urban areas in high numbers. They however found little or no formal housing, so they were forced to settle in informal settlements such as Msunduza. These areas grew to an extent that they were uncontrollable, and by the 1980s, about 60% of the urban population in both Mbabane and Manzini were living in informal settlements. The structures built in these areas were temporary shacks or traditionally built adobe houses at first, but with time the old structures began to be replaced with structures constructed using modern materials and methods. This led to Town Councils introducing a ban in informal settlements preventing the construction of permanent structures.

Due to the inaccessibility of these areas as well as the steep slope, these areas had been disregarded for development by the formal sector. So, there were no services provided which led to unhealthy conditions, infectious diseases, crime, and prostitution as the population continued to increase. As the cities grew, these areas became barriers for urban expansion which reached a point where these challenges had to be addressed. The government was alarmed by a Cholera outbreak in 1983 which resulted in deaths in Msunduza, and it was clear that a sustainable solution to the provision of accommodation and services was required in these informal areas. This outbreak, and Cyclone Demonia in 1984 which destroyed infrastructure, forced the government of Eswatini to seek international assistance. The World Bank, USAID, UNDP, KfW and ODA all contributed resulting in the formation of several policies such as a draft National Housing Policy, a National Housing Implementation Plan, Institutional Framework for the NHP, Human Settlement Authority Act and the National Housing Board Act among others.

MHUD (2007) lists a sequence of historic events believed to be origins of the crisis which resulted from lack of access for its citizens to serviced land:

- “Concessions granted to foreigners;
- Formalising those concessions by the colonial power;
- Partition into Crown Land, Title Deed Land and Swazi Nation Land;
- Development of towns on Title Deed and Crown Land;
- Exclusion of Swazis from formal residence in the towns;
- Tenure in towns restricted to renewable Temporary Residence Permits;
- Allocation of steep, unsustainable and unserviced land for urban Swazi residents;
- Introduction of the building ban to prevent further uncontrolled development.”

The historical narrative above gives a sequence of changes mainly in the political system which influenced the changes in the focal system (Msunduza). The inaccessibility to the town (only accessed through temporary permits) was the main driver to the development of the informal settlements.

Msunduza, located on the hills which form the backdrop of Mbabane, has not been spared from the changes which occurred at scales above it. The structural conditions, governance issues, and densification, along with pressures transferred from the larger scale, has made this area vulnerable to climate change.

Figure 6.2 below summarises the historical events which affected the resilience of the settlement and eventually shaped it to the current spatial condition. These events are mixed; from political events, and social events, to climatic events as well as development programs. These selected events had extreme impacts on the climate change resilience of Msunduza and shifted the system from one phase to another in the adaptive cycle as presented in the next section.

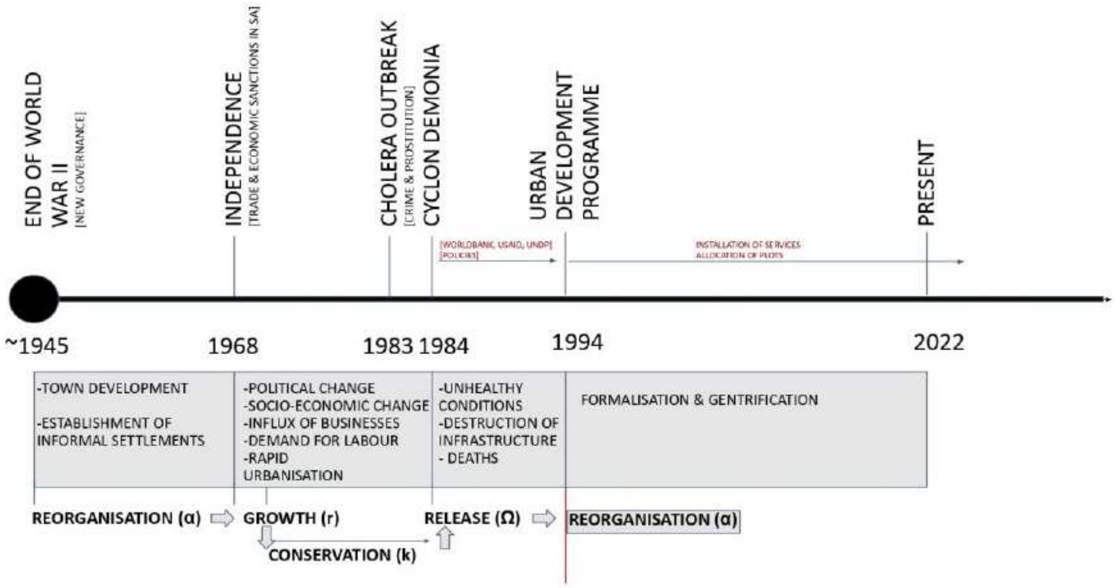


Figure 6.2. Historical timeline of events that affected Msunduza

Climate conditions continue to affect economic development, and the frequency and intensity of disaster episodes has gradually increased over the past 15 years resulting in moderate to devastating disasters especially in Msunduza. The NDMA reported that between 2001 to 2018, Eswatini was hit four times by different severe storm events, as well as cyclone Eloise which was the fifth (NDMA, 2020). Cyclone Eloise affected a total of 777 houses of which a majority were in upgrading areas (NDMA, 2020). At present, mitigation and adaptation of the neighbourhood components such as the environment, infrastructure, population, and buildings, are the key management objectives. The timeframe for assessment spans decades, therefore history is used to determine the dynamics of the neighbourhood.

6.3. System evolution

Change in any system is always occurring and these changes should not be ignored. A system experiences both gradual or rapid changes (Resilience Alliance, 2010). Most systems are dynamic and change over time, in most cases following four phases: growth, maintenance, collapse, and reorganisation as discussed in Chapter 2 of this dissertation. The adaptive cycle model gives understanding of how a system changes over time. Understanding a system's unique pathway and current position through the phases of the adaptive cycle allows for proper interventions in the system.

Msunduza was observed through the lens of the adaptive cycle to understand the dynamics of this system. The cycle was observed over a larger and more complex system as per the narrative in the previous section. Observations show that the system changed when several larger (economic, political, and social) changes pushed the system to the next phase. The movement of the Msunduza settlement through the adaptive cycle phases are discussed in the sub-sections below.

6.3.1. Reorganisation phase [1945]

The cycle started at this stage at the formation of the informal settlement when World War II ended in 1945. The change of the global political system had an effect even on smaller systems, as towns and cities started to develop. The change of the global political system is seen as one of the major drivers of the formation of the focal system. Since the people of Eswatini had no right to live in towns, the change of towns and rigidity of the local political system influenced the formation of informal settlements as residents had to settle around towns. These areas were without services. The natural systems responsible for addressing climate change were replaced by temporal structures at the foot of a hill in the case of Msunduza. Employment opportunities in Mbabane also shaped the formation of the informal settlement and shifted the system to the growth phase.

6.3.2. Growth phase [1968]

The informal settlement continued to grow as the town (Mbabane) grew and resulted in more employment opportunities. These opportunities resulted in rapid urbanisation. Due to the restrictions that were still in effect, people who came to seek employment opportunities had to settle at Msunduza area and other informal areas. The independence of 1968 caused even more influx of business creating a demand for labour and therefore even more rapid urbanisation. Growth of the informal settlement also increased the vulnerability of the settlement to climate change since more residents required more land for building, and more food to survive, resulting in the destruction of ecosystems which are also crucial in addressing climate change.

6.3.3. Conservation phase

As the Mbabane town stabilised, the informal settlement also stabilised. Some residents were employed in the town, and others had opened small businesses in order to survive the expensive urban life. The residents had established a way of living in the current unfavourable conditions. As the residents got comfortable in these areas as they were no longer required to renew their temporary residence, some started building permanent structures, but they were eventually banned from doing so. The areas were disregarded for development by the formal sector, and they were not permitted to build formal structures. Resilience was therefore not built into the settlement to address flooding, extreme heat, and strong winds. The large population was also running out of space to develop.

6.3.4. Release phase [1984]

This area became vulnerable to infectious diseases, crime, prostitution, and climate change disturbances. There was eventually a cholera outbreak in 1983 resulting in deaths, and shortly thereafter, Cyclone Demonia which destroyed structures at Msunduza.

This was evident enough that a sustainable solution to the provision of affordable and proper accommodation and services was required in these informal areas. This outbreak and Cyclone Demonia in 1984 forced the government of Eswatini to seek international help.

6.3.5. Reorganisation phase [1994 - present]

Following the collapse of the structures in the informal settlements, Eswatini sought international help, and following the formation of new policies, an Urban Development Programme started with the intention to upgrade informal areas. The programme aimed to push the settlements to cross the threshold of informality to a formal state. The system therefore started to reorganise, and the Eswatini National Housing Board was tasked to install services and formalise the Msunduza informal area. Services such as electricity, roads, and drainage channels were installed. The residents were further allocated plots. This pushed the system into the next growth phase.

6.3.6. Second growth phase [present]

In this phase, gentrification comes as temporal, adaptable structures are replaced with rigid formal and permanent modern buildings which are not flexible and therefore less adaptable. The function of these settlements of providing affordable services is also affected with the introduction of formal structures, tenure, and rates. The focal system is currently at this phase of growth and consolidation. However, the system remains vulnerable to perturbations caused by climate change.

Based on the understanding of the issues of concern or risks of climate change to informal settlements, identifying the specific components of the settlement which need to respond to sustain the valued attributes of informal settlements, and the formation and dynamics of the study area, it is critical to establish the vulnerability of the selected study area using the accumulated information about informal settlements in general and the study area. The following section presents results of the resilience assessment conducted through fieldwork.

6.4. Resilience Assessment

To assess the resilience of Msunduza settlement to the impacts of climate change, fieldwork was conducted to assess three subsystems of the settlement, namely infrastructure, buildings, and resources. The attributes of spatial resilience (diversity, redundancy, modularity) were investigated to determine areas of the settlement where diversity, redundancy, and modularity is a concern, which might render the settlement vulnerable to a loss of function. Diversity in a system allows it to adapt to shocks and stresses in different ways according to the nature of the crisis (Peres, 2016). Redundancy is known as a 'backup' (Zolli & Healy, 2012:13) for the system in cases where the system is affected. It increases response diversity of a functional group and therefore resilience of the system. Then modularity refers to a system that has an internal structure which is made of simple elements that can accumulate or decouple in response to change. The following sections present the findings concerning the adaptive capacity of infrastructure, buildings, and resources to determine vulnerable areas.

6.4.1. Infrastructure

Infrastructure, which was assessed through a mapping method, consists of components responsible for responding to climate disturbances, such as water management systems expected to respond to flooding and overheating; water supply expected to be resilient to drought and overheating; energy systems and telecommunication systems which should remain operational during storms and flooding disturbances; as well as movement systems expected to offer alternative escape routes during flooding and storms. The resilience of each of these components was assessed.

6.4.1.1. Water management systems

The expected extreme weather events resulting from global climate change, along with the reduction of impervious surfaces, demand proper storm water management systems to keep cities functional. Sustainable urban water management systems, which use natural means to capture runoff at its source, have emerged as a preferred means of managing storm water (Sletto et al., 2019). In the resilience discourse however, diversity is considered critical to keep the function of managing water effective despite disturbances contributing to the destruction of this function. Diversity has therefore been assessed in the study area to determine the adaptive capacity of the existing storm water management systems.

In this study it is proposed that the functional groups of a storm water management system that physically make this system function include what will be referred to in this study as water type, water infrastructure, and water absorbers (Table 6.3).

Table 6.3. Proposed functional diversity of a water management system

Type	Infrastructure	Absorbers
Runoff	Storm drains	Natural streams
Water from roofs	Green cover	Wetlands
Greywater	Water tanks	Storage tanks
Ground water	Public sewer lines	Ground water absorption
	Road surfaces	Treatment facilities

'Water type' refers to runoffs, water from roofs, greywater and even groundwater. This functional group consists of the water which needs to be managed to ensure the storm- water management system functions in a healthy manner. It has been observed at Msunduza informal settlement that greywater ends up in storm water infrastructure if not well managed. Further, as to be observed in later sections, waste should be properly managed to keep storm water management systems functioning properly. The second functional group, 'water infrastructure', is the functional group which was assessed in this study, and this included both green infrastructure and grey infrastructure which manages water: storm drains, green cover, water tanks, public sewer lines, and road surfaces. The last functional group refers to the destination where storm water is channelled to, such as natural streams, wetlands, storage tanks, ground water absorption, treatment facilities, and other end of pipe solutions.

General observation of the settlement shows a great need for different actors to manage storm water due to the steep terrain as well as the heavy rainfall received in this area. Further, greywater requires proper management in a densely populated area such as this one to keep the area in good sanitary condition.

The results of the assessment show that storm drains exist to manage water along a few of the streets at Msunduza. Such storm drains are fragmented and haphazardly developed with undersized culverts and channels. Most roads, however, do not have storm drains, and in those which do, the storm drains are often blocked by accumulated solid waste due to poor or no maintenance, as well as inadequate municipal waste collection. This results in most of the storm drains being unfunctional due to the blockages. Some storm drains are blocked by rocks which further trap dirt and affect the functioning of this system (Figure 6.3).

The existing storm drains channel water to natural streams; however, due to blockages some discharge water into homesteads, roads, or unbuilt land, which has eroded most of the areas downstream.

Figure 6.3. Blocked storm drains at Msunduza

Most parts of Msunduza are covered with vegetation (Figure 6.4 below), clearly due to the high rainfall received in the highveld in which the study area falls. Almost all homesteads have at least one fruit tree, and the common ones are avocado trees. This probably is a result of a previous project which had to do with planting fruit trees in every homestead, as the trees are of the same type of trees and same size, and likely the same age. Besides providing food, these fruit trees assist in partially absorbing storm runoff and reducing its speed.

Grass cover, on the other hand, is not as dominant, probably due to heavy traffic and cultural practices of clearing homes to leave the ground bare. To avoid the high costs of maintaining lawns, residents opt to clear their homesteads of grass to keep them neat and clean. So, in most areas, especially within homesteads, there are trees within the homestead but bare ground underneath the trees and a better part of the yard.

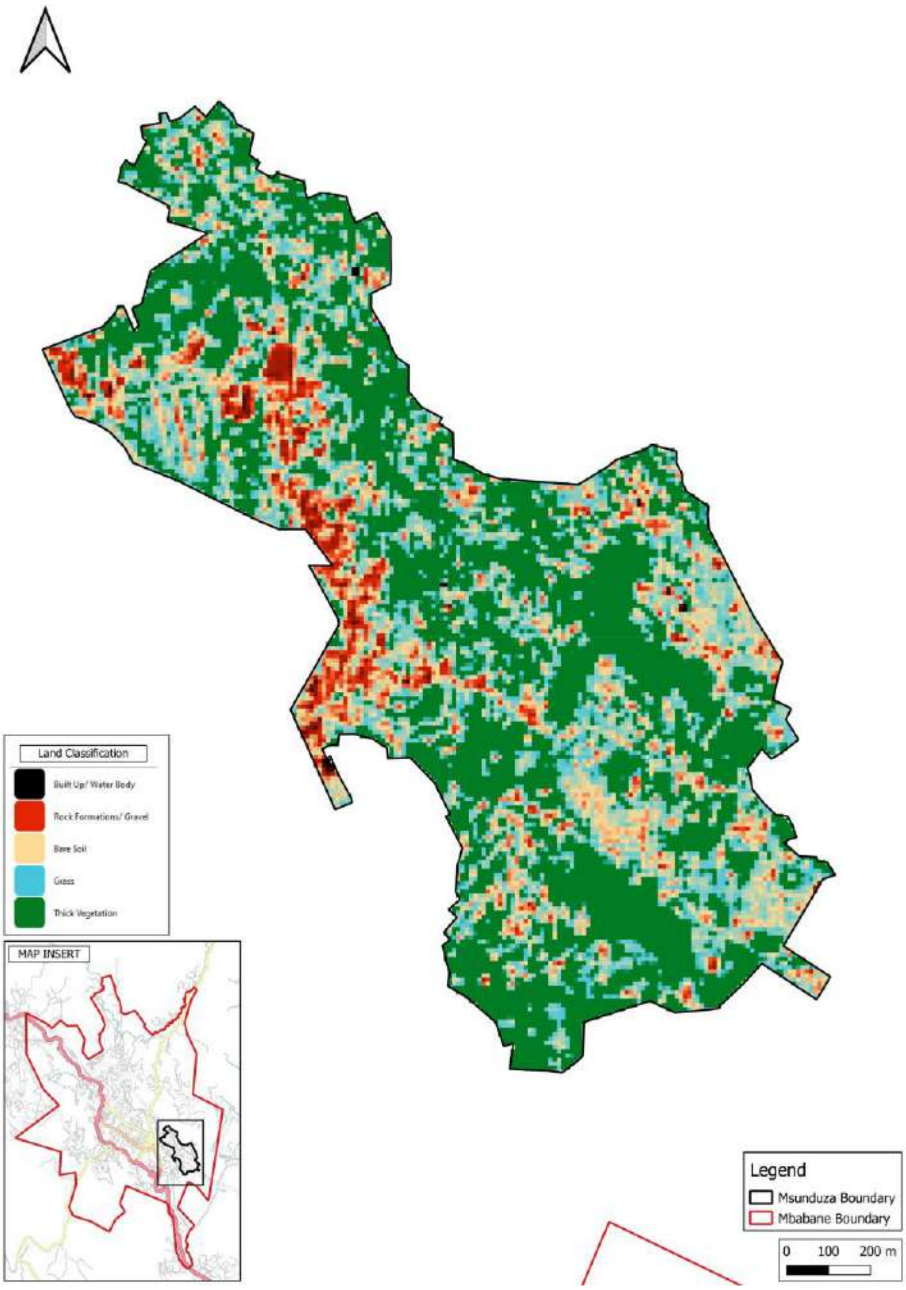


Figure 6.4. Vegetation cover at Msunduza

No public water tanks were observed besides the main water silo which supplies the whole Msunduza with water. There are also very few homesteads that have water tanks, as discussed in the next sections. This means rainwater is not harvested but freely runs from roofs to bare ground and finds its way to storm drains, or flows from homestead to homestead leaving a trace of damage on the ground. This overwhelms the storm drains, especially in heavy rainfall events.

The role of public sewer systems in water management is to assist in protecting water quality and ensuring public health. At Msunduza, only a fraction of the households has access to the public sewer system. As a result, wastewater from kitchens and bathrooms is disposed of to storm drains as this wastewater was observed running downslope in drains and there was an unpleasant smell from this water in most parts of the area. This has resulted in unsanitary environmental conditions as this water is discharged to waterways and natural streams. Such dirty water also contributes to the blockages of storm drains and further pollutes streams which are a source of drinking water to most residents in this area. The storm drain systems are therefore overwhelmed as they drain both wastewater and rainwater at Msunduza.

The road surfaces at Msunduza are finished with either tar or concrete material. A majority of the roads are gravel or have peeling concrete pavement. The impervious cover of the neighbourhood, mainly the roads, was developed without consideration of downstream drainage impacts. No porous road surface such as brick pavers was observed in the walkabout at Msunduza. The types of roads found at Msunduza are profiled in Table 6.4 below.

Table 6.4. Types of roads at Msunduza

	Type	**Image**	**Description**
1	Concrete roads		Surface: Concrete Condition: Good Porousness: Not porous Storm drains: Yes
2	Sulphite roads		Surface: Tar Condition: Average. Most have potholes. Porousness: Not porous Storm drains: Some

	Type	Image	Description
3	Strip concrete roads		Surface: Concrete Condition: Poor Porousness: Not porous, but unpaved between the strips which is porous in non-busy roads Storm drains: No
4	Gravel roads		Surface: Gravel Condition: Poor Porousness: Not porous due to its compactness, but muddy on rainy days Storm drains: No
5	Concrete footpaths		Surface: Concrete Condition: Average Porousness: Not porous Storm drains: Yes, but not functional due to erosion

To reduce high costs of maintenance, the drainage systems have been engineered with maximum efficiency, resulting in low response diversity. This makes the water management system vulnerable to collapse from even small shocks such as those caused by heavy rainfall and flooding. The parts of the settlement with only one response to storm water management will result in the destruction of this response and therefore the destruction of the entire functional group. Vulnerable areas (claimed not to be resilient to flooding and drought by this study) were mapped as shown in the diagram below. These are areas with no diversity in water management systems, such as areas with vegetation only but without storm drains and sewer systems, and these are vulnerable to flooding. The presented Figure 6.5 below further shows areas with a diversity of water management systems therefore considered to some extent resilient to flooding as they better manage runoffs from heavy rainfalls.

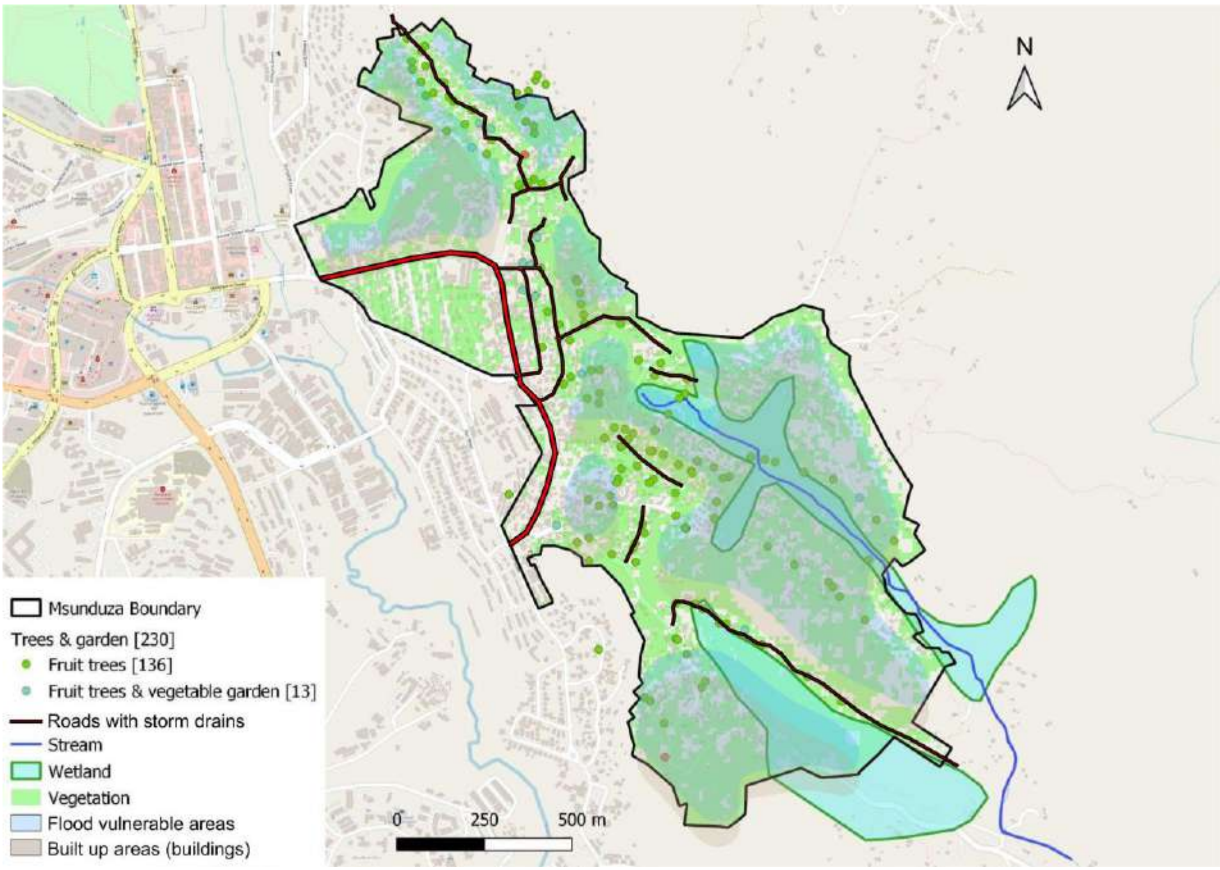


Figure 6.5. Areas of Msunduza vulnerable to flooding

It is evident from Figure 6.5 above that a larger portion of Msunduza is vulnerable to flooding due to the lack of alternative water management systems to reduce run-offs that eventually affect houses and residents of such areas. This explains why the interviewed participants claimed that these upgrading areas are more vulnerable to flooding.

6.4.1.2. Heat management systems

Considering the forecast of rising heat events due to climate change (IPCC, 2014), temperature increases within urban environments are of concern. As urban environments fail to cool down and limit indoor thermal increases, it is critical to develop cooling strategies in these areas and further ensure their resilience to keep these environments liveable even in extremely hot weather conditions. While it is known that temperatures are increasing worldwide, the impacts of urban heat islands differ depending on the urban structure, local climate, and location of the city. This calls for understanding of each context to address its impacts. In this study, a few factors that may affect the urban heat island are highlighted. Cooling components within the informal settlement were further identified. Cooling components could be natural or manmade, however the focus of the study is on natural means because of affordability reasons. The adaptive capacity of the cooling system is determined, which is the main focus of this section. Components that were observed and mapped are those that are responsible for mitigating heat stress, such as green cover, natural streams, swales and wetlands.

As stated in the previous section, a better part of Msunduza is covered with vegetation. Big avocado trees were observed in almost all homesteads, along with other fruit trees such as banana trees, orange trees, and lemon trees in some areas. Vegetation is known to cool the environment mainly through evapotranspiration as well as providing shading to residents and also shading surfaces that would have absorbed radiation. In this area there is no vegetation in the form of parks, and there are limited street trees. The vegetation along streets is the overgrown unmonitored vegetation. There are neither green roofs nor green facades. The green is clearly in private spaces more than in public spaces.

It is noted that looking at the high density of buildings, the development of green 'pockets' in private spaces can be more effective in the attempt to cool the neighbourhood. Cities in first world countries such as Paris and Rotterdam promote green facades and terraces, and there is a subsidy program of green roofs that was implemented in Rotterdam (Kleerekoper et al., 2012) which can be applicable even in developing countries. There are still areas which are not covered by vegetation at Msunduza, normally in the vicinity of the houses and obviously vehicle roads and pedestrian paths, as well as the area closer to the formal city.

There is a stream running through the settlement, and another flowing along the settlement which contributes to cooling of the settlement especially in areas closer to the stream. Water is claimed to have a cooling effect of 1-3 degrees Celsius to an extent of 30 to 35 metres (Kleerekoper et al., 2012). Another study showed that a cooling pond of 4 metres by 4 metres has a cooling effect of 1 degree Celsius at 1 metre height measured at 30 metre distance from the pond (Robitu et al., 2004). Water cools an area by evaporating and by absorbing heat or carrying heat out of the area through moving water in rivers. However, only a fraction of the settlement experiences the cooling effect of the water bodies.

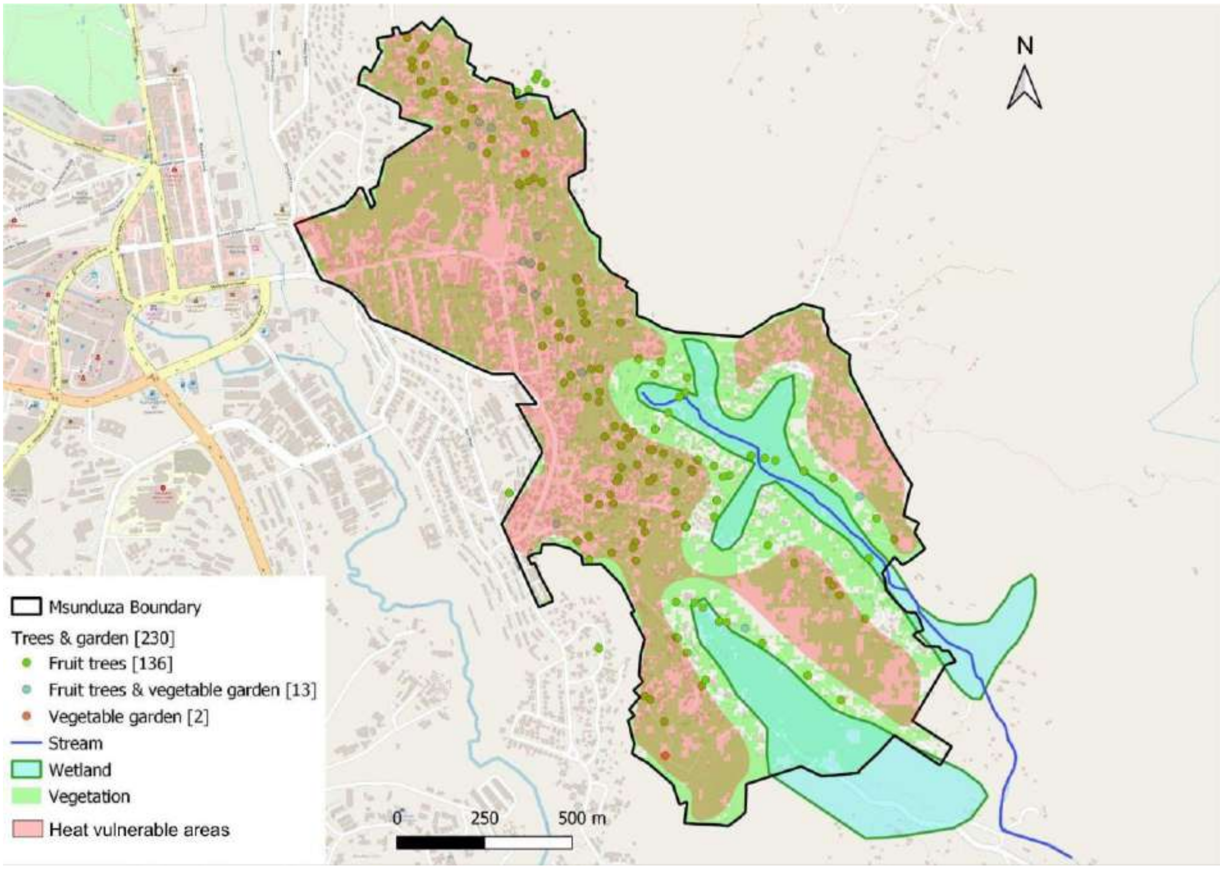


Figure 6.6. Areas vulnerable to extreme heat

It can be concluded that the southern part of Msunduza has good response diversity to extreme heat as there is a mix of vegetation, wetlands, and a natural stream. This makes this area have a higher adaptive capacity to extreme heat, but an increased flooding risk. The top part of this settlement however has poor response diversity to extreme heat (Figure 6.6). Looking at the decreasing vegetation with time and the lack of alternative cooling systems, the area shows a decline in diversity of cooling systems and increase in vulnerability to extreme heat. This is also an area with a higher building density, which also reduces the permeability for cool air to flow.

6.4.1.3. Water supply systems

The water supply system is understood in this study to include three functional groups which are water sources, water infrastructure, and water consumers. Water sources include rainwater, underground water, dams, and streams. Water infrastructure includes the pipe system, boreholes, water storage systems and other technologies, or systems which draw, store, or transport water to the users. Water consumers can include agricultural systems, industry, and people, among others. Water supply system components sought in the settlement were drawn from the sources and water infrastructure functional groups and include community water tanks, public water supply system, community boreholes, and natural streams. However, only public water supply was identified and mapped at this part of the study (private solutions are discussed in the next section). The aim was to determine the level of redundancy which is referred to as a ‘backup’ or ‘insurance plan’ (Zolli & Healy, 2012) for the system at a time when things go wrong. Where redundancy exists, the response diversity also increases and that increases the resilience of a system. Water supply systems were therefore sought and mapped to understand their spatial arrangement so that areas where they overlap or where there is redundancy are easily identifiable.

The results show that the main source of water in this area is the centralised public water supply by Eswatini Water Service Corporation which reaches a better part of this area (Figure 6.7). It was observed however, that even though some areas are closer to the water supply pipeline, they did not connect to this line possibly since the minimum service fee is not affordable to some residents. Some residents relied on the stream as a source of water, the cleanliness of which is questionable. It was observed as well that most of the houses were not plumbed even when they are close to the water pipeline.

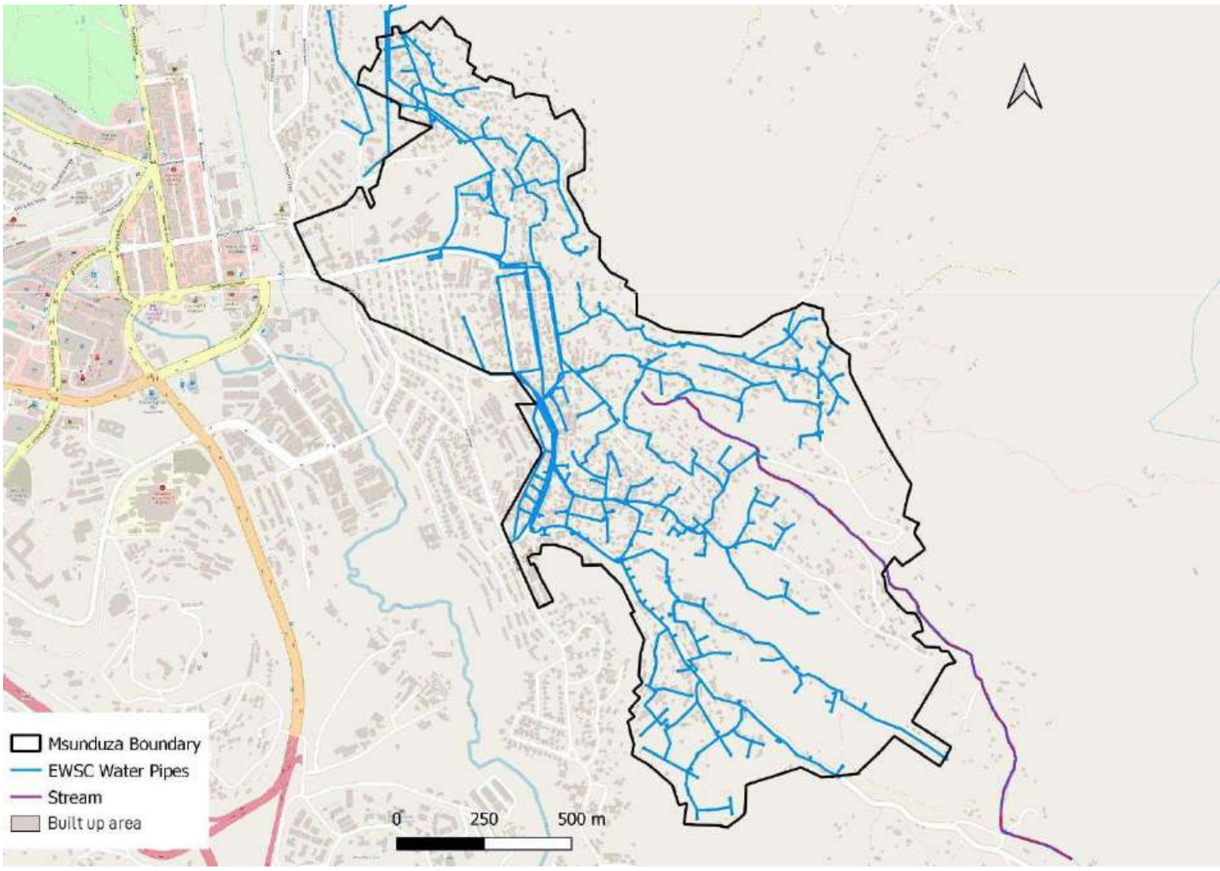


Figure 6.7. Water supply at Msunduza

There were very few water tanks observed in this area. A water silo observed forms part of this centralised system and supplies the whole area with water. Some residents opt to use water from the natural streams, possibly due to high costs of public water supply. This water however is polluted in some areas due to uncontrolled grey water flowing from storm drains into these streams.

The lack of diversity and redundancy in water supply systems lead to a better part of Msunduza being vulnerable to water supply interruptions, as when the dams from which the public water is drawn dry up due to extreme heat and absence of rain, there is no alternative water source on which residents can depend. It is the reason that when drought was declared a natural disaster in Eswatini in 2016, during which the city of Mbabane had to ration water supply. Water was scarce and if these disasters lasted longer, the residents would have eventually run out of water. Such a time is predicted in future if alternative water sources and decentralised water supply systems are not introduced.

It can be concluded that the centralised public water supply network results in vulnerability to sudden dramatic changes (Walker & Salt, 2006). The water supply system can be considered brittle as it is unable to adapt or evolve to change and therefore becomes vulnerable to disturbances and collapse. A disturbance in the main water supply system cuts off water supply in the whole area of Msunduza. A decentralised water supply system is considered more resilient since a disturbance in one area would not affect water supply in the rest of the settlement, and more water sources are proposed in such areas to improve the adaptive capacity. It is however a concern from the perspective of a mechanistic approach that building redundancy is costly because it is a duplication of existing functions (Anderies, 2014). This is clearly the approach in which the settlement was developed, which leads to its vulnerability.

6.4.1.4. Energy sources

Redundancy is a system attribute that was also assessed to determine the resilience of energy systems in this study area. Energy sources sought include public electricity supply, solar panels, generators, and firewood.

It was determined that currently the primary source of energy at Msunduza are fossil fuels, and the energy is supplied by the Eswatini Electricity Company with 70% of it imported from the neighbouring country, South Africa. According to Ratshomo and Nembahe (2019), in 2016, 90.5% of the total energy generated in South Africa was from fossil fuels. Eskom in South Africa has the monopoly on electricity provision in that country and exports electricity to Eswatini Electricity Company which also has the monopoly on electricity provision in Eswatini.

Challenges start at this level and spread down to smaller systems. Redundancy is however observed at national level as various power stations supply the national electricity grid with some generators partly meeting redundancies. This however is not observed at settlement level which is covered by one power station.

Energy lines reach almost the whole area of Msunduza, however there is still a low percentage of residents that do not afford to connect to these energy lines. It is assumed that such households use firewood as a source of energy for cooking and warming their houses.

This centralised energy system is obviously massive in scale, making it vulnerable to sudden climate events. When there are disturbances in this main power supply caused by flooding or storms, there is no alternative energy the residents can use. No solar panels and generators were observed in this settlement. Residents may go without electricity for days until power lines are restored. The energy supply system has a low adaptive capacity across the whole settlement.

Adopting renewable energy sources is still viewed as the better response to response diversity and increasing the resilience of the system. These energy sources, when decentralised, can provide more diversity and stability in the energy network (Ahern, 2011).

6.4.1.5. Telecommunications

Eswatini Post and Telecommunication is the only provider of fixed telecoms, with telephone lines running along roads. At Msunduza, however, none was observed. The assumption is that residents only rely on mobile phones from two providers, Eswatini Mobile and Eswatini MTN, for communication. Mobile phones provide a more resilient way of communication since if one network tower is affected, another one in a different but nearby location can cover the same area for the network to keep communication going.

6.4.1.6. Movement systems

The form of the street layout varies from the area closer to the formal city to the more informal area at the foot of the hills of Msunduza. The streets closer to the city can be classified as a warped parallel grid street layout. According to DHS (2019), this type of a layout consists of blocks that form long narrow rectangles and L-shapes and has fewer blocks and access points compared to the traditional grid. This makes this grid less permeable than the traditional grid and it is not pedestrian friendly since pedestrians have to move longer distances around the blocks.

As you move deeper into the neighbourhood, the street patterns slightly change as they are disconnected and curvilinear, adapting to the steep slopes of Msunduza. Such a system according to DHS (2019) is called a Loops and cul-de sacs (dead-end) street layout, which makes it difficult to find one's way in a neighbourhood. Access to such neighbourhoods is through one or two higher order streets. This pattern has even fewer access points and therefore low connectivity which reduces movement resilience, and delays access to affected areas. This pattern also requires careful planning of storm water management systems to drain water out of such neighbourhoods.

Connectivity of the physical road network was assessed at Msunduza as shown in Figure 6.8 below. It is clear that the local road system, as discussed in the previous paragraph, does not represent a well-connected internal layout of vehicular roads and pedestrian paths and is further limited to a few access points linking it to the larger urban system. Good connectivity is only witnessed where the informal settlement connects to the city, as highlighted in the diagram. This means if the southern roads are inaccessible because of impacts from storms, this will disturb the whole southern block, making it inaccessible to emergency services.

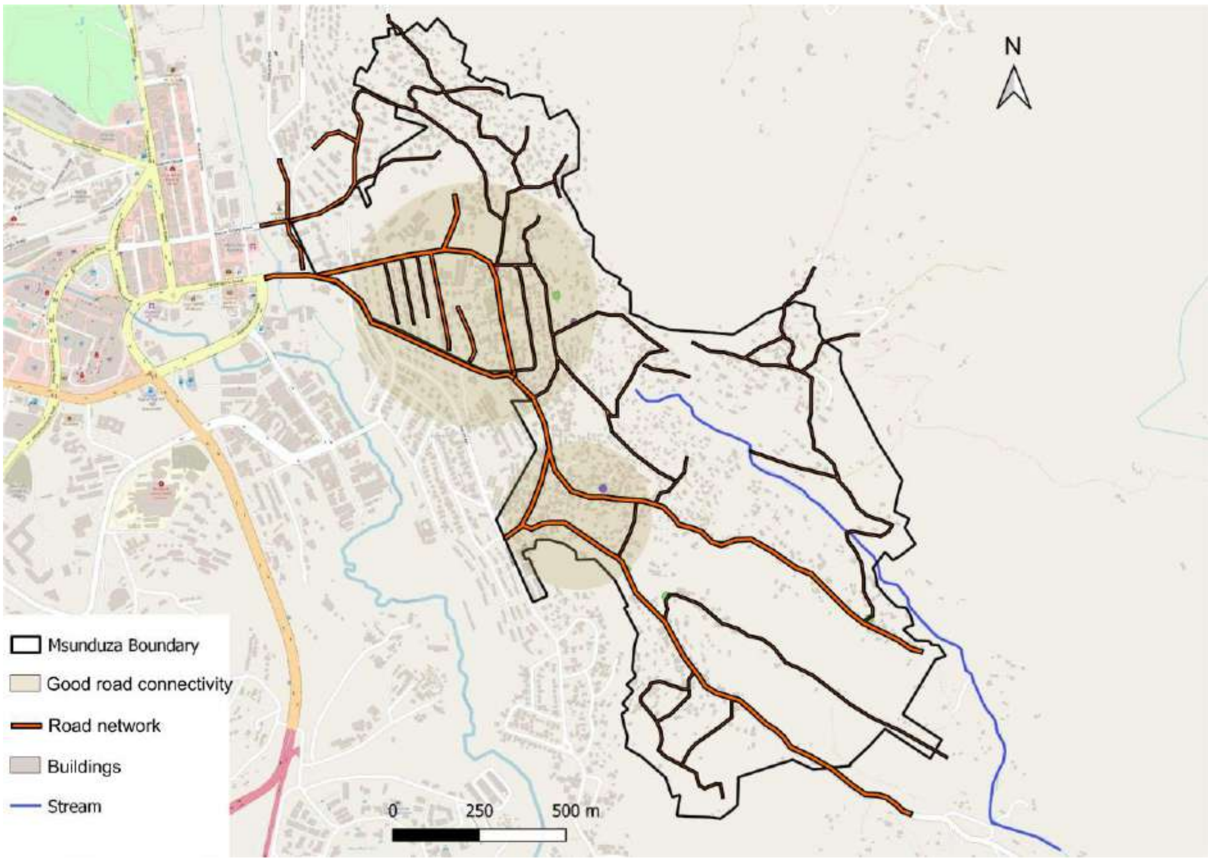


Figure 6.8. Connectivity explored in the road network of Msunduza

6.4.2. Buildings

The ‘building’ functional group was also assessed. Buildings can be considered as subsystems of the informal settlement. Since changes in the subsystems affect the focal system, it is vital to also assess their resilience. The study on buildings used a quantitative method to collect and analyse data. The analysis used basic descriptive statistics since only frequencies were required. The buildings assessed were sampled from a population of all buildings at Msunduza to understand the building typology and how these typologies adapt to extreme heat, flooding, and storms. Two hundred and thirty (230) buildings were sampled, including households comprising buildings ranging from a single building to five buildings per household.

Materials used for the building envelope was assessed to understand how they respond to heat and flooding. Diversity and redundancy of energy sources and water supply were assessed, as well as the building site, to understand its contribution to the adaptation of the houses to strong winds, flooding, and extreme heat.

6.4.2.1. Building typology/form

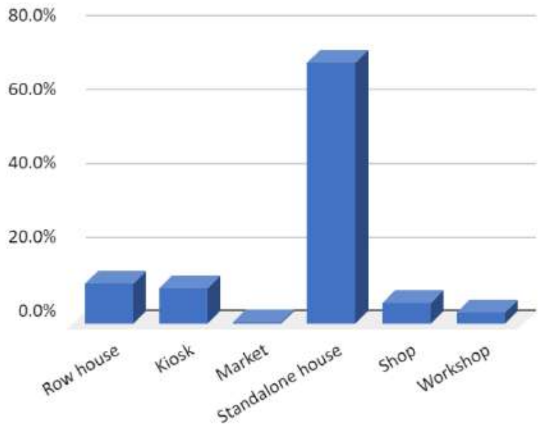
Response diversity of buildings which relates to the mix of typology was assessed at Msunduza. Results show that there is a mixed land use in this area having retail, residential, industrial, and civic spaces. Buildings identified were row houses for rental, standalone houses for family dwelling, shop, kiosk, market, and workshop to determine functional diversity. The buildings were grouped according to type and function (Table 6.5). Further, typology was determined by observing the use of materials of the building envelope to determine response diversity to flooding, extreme heat, and storms. The following materials were identified: adobe blocks, metal sheets, wood, concrete blocks, and bamboo. In the table below, the buildings identified at Msunduza are profiled to understand their mix and adaptability.

Table 6.5. Building typology at Msunduza

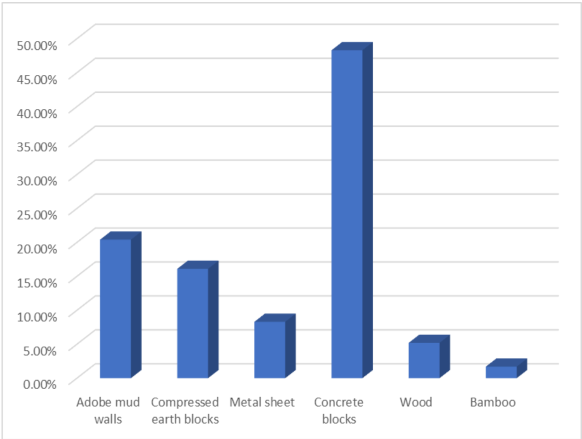
Type	Example	Description
Standalone house	 	**Material**: Concrete blocks (54.2%), adobe mud blocks (23.5%), compressed earth blocks (17.9%), metal sheets (2.5%) and wood (1.2%). Almost all houses are roofed with metal sheets except for 3.1% roofed with Harvey tiles. **Percentage of buildings**: 70.4% **Adaptability**: General poor climate adaptation (discussed in sections below)

Type	Example	Description
Row houses	 	**Material**: Concrete blocks (36%), adobe mud walls (32%) and compressed earth blocks (28%). Row houses with metal sheets only make 4%. All sampled houses are roofed with metal sheets. **Percentage of buildings**: 10.9% **Adaptability**: General poor climate adaptation (discussed in sections below)
Shop		**Material**: Concrete blocks (84.6%), adobe mud blocks (7.7%) and compressed earth (7.7%). All shops are roofed with metal sheets. **Percentage of buildings**: 5.7% **Adaptability**: Poor climate adaptation
Kiosk		**Material**: Metal sheet walls (40.9%), wood (40.9%), bamboo (13.6%) and concrete blocks (4.5%). All kiosks are covered with metal sheet roofs. **Percentage**: 9.6% **Adaptability**: Average climate adaptation (discussed in next sections)
Workshop	 	**Material**: Metal sheet walls (100%) and metal sheet roofing **Percentage of buildings**: 3% **Adaptability**: Average climate adaptation (discussed in next sections)
Market		Material: Concrete blocks and Metal sheet roofing (100%) Percentage of buildings: 0.4% Adaptability: Average climate adaptation (discussed in next sections)

The functional diversity of buildings is very low, with most of the buildings being standalone houses (70.4%) and row houses (10.9%) for rental, and a few for business purposes as presented in Figures 6.9a and b. This settlement can therefore be called a residential settlement with a few other buildings used by residents to generate income.



a.



b.

Figure 6.9. a. Building typology at Msunduza, b. Building materials used at Msunduza

The most common material used is concrete blocks. However, looking at the historical timeline (Figure 6.2) it is surmised that since gentrification started, the use of material has changed from adobe mud blocks to concrete blocks, and the condition of the houses are changing from houses which are temporal and easy to manipulate (more adaptable), to houses which are more formal and less flexible. Gentrification started after an attempt was made to install infrastructural services and issue titles to some residents that managed to contribute towards the UDP.

The current residential response includes informal responses, such as temporal buildings built of adobe blocks and not aligning to the building regulations, high density row houses, government houses, as well as modern buildings with full title. The temporal informal adobe block house enables quicker responses in the case of disturbances caused by climate change. The modern buildings with full title have very slow rates of change and response to change in larger systems. Adaptive capacity of the houses is further discussed in the next sections. The two types of adaptation, which are soft adaptation and hard adaptation (Coley, Kershaw & Earnes, 2012), are both considered. Hard adaptations are those integrated to the design, which might be challenging to alter, and soft adaptations are those which can easily be changed, or which occupants can adjust such as opening windows.

6.4.2.2. Building envelope (heat adaptation)

Heat adaptation of buildings was assessed at building level. The idea is not only to counteract rising temperatures and provide a comfortable environment even in extreme heat, but also to maintain or even reduce energy consumption while keeping the building comfort level adequate.

The houses at Msunduza were assessed to determine their heat adaptation by observing passive climate control measures such as roof overhangs, cross ventilation and use of material. This was done by measuring the percentage of houses with and without roof overhangs, use of cross ventilation (opposite windows), high thermal mass material and reflective paint. To enable evaluation of adaptation to overheating, a rating scale was developed: poor adaptation, average adaptation, and good adaptation. Poor adaptation refers to the lack of response diversity to overheating. Lack of diversity is when there is a single or no response to extreme heat. Average adaptation refers to houses with two components that respond to heat such as the existence of roof overhangs which shades radiation especially from the east-west, and existence of directly opposite windows that enables cross ventilation. The sizes of the windows were not recorded, but they had to be multiple to be considered. Good adaptation refers to buildings which had three or more items which respond to heat. The kind of response to extreme heat was determined before rating the level of adaptation of each house.

The results show that 73% of houses, either have no roof overhangs or have roof overhangs that do not provide shading. Only 27% of the sampled houses have overhangs which provide shading (Figure 6.10)

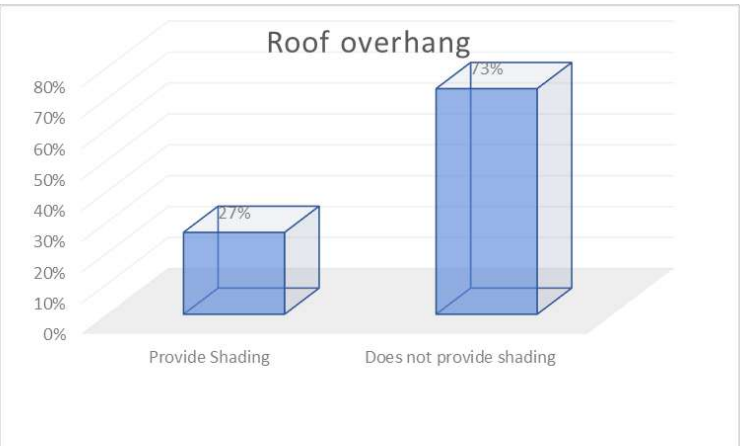


Figure 6.10. Roof overhangs chart

Further, the results show that only 23% of the houses at Msunduza have cross ventilation (Figure 6.11). The rest of the houses either have windows on one side of the house only or have windows which are not directly opposite to each other. Bigger houses with parallel rooms make cross ventilation a challenge.

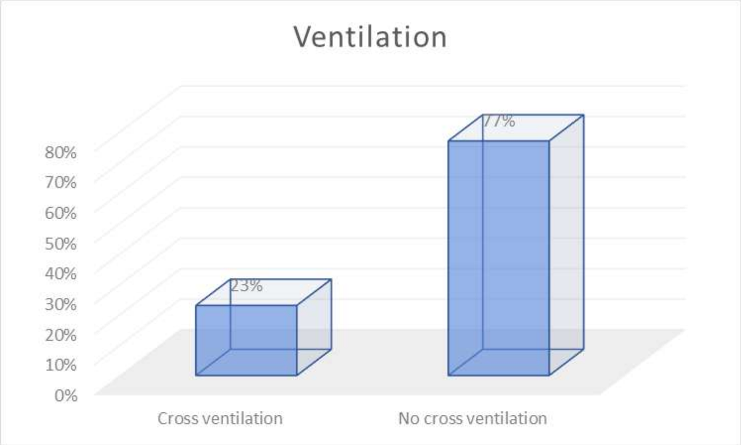


Figure 6.11. Cross ventilation results

Material also contributes to the thermal comfort level in a building. Materials such as metal sheets have a short thermal lag time, meaning they absorb and release heat quickly. Clay bricks on the other hand have a long thermal lag. Materials with high thermal mass can reduce energy consumption in a building and increase thermal comfort. Studies have shown that increasing the thermal mass of a building leads to a decrease in maximum temperature or overheating in the building (Artmann et al., 2008). Night ventilation however may be key in moderating the temperature at night. The results show that there are materials with high thermal mass such as compressed earth blocks and adobe brick walls, as presented in Section 6.4.2.1.

When rating the buildings, the marketplace, public sitting area and a percentage of kiosks were the only structures which had traces of good adaptation (Figure 6.12). The figure below shows that most of the typologies have poor adaptation, meaning they have one or no component of the building which responds to overheating.

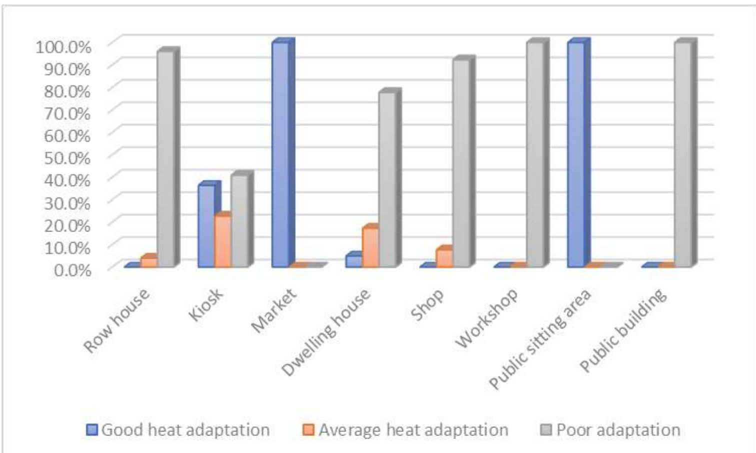


Figure 6.12. Rating of heat adaptation per building type

When observing the spatial distribution of the buildings within the settlement (Figure 6.13), there is no discernible pattern to the distribution of buildings with different ratings (poor, average, and good adaptation).

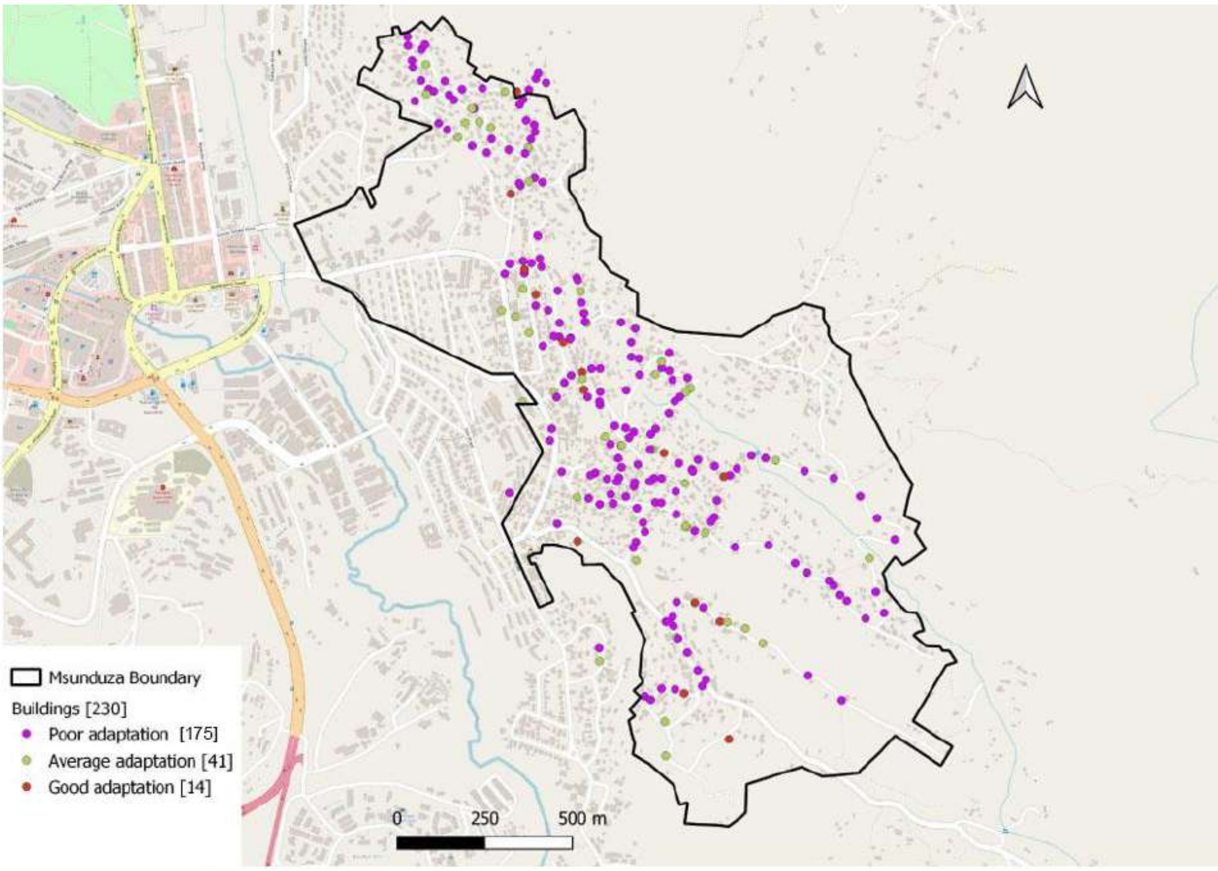


Figure 6.13. Spatial distribution of heat adaptation

6.4.2.3. Building envelope (flexibility)

Flexibility is also an attribute that was assessed in the buildings to determine their adaptability. Besides determining adaptability as a response to demographics (and climate) change, they present a need for flexible architectural solutions which considers the relationship of the houses to people's changing expectations as well as changes in the context. Flexibility in this context refers to buildings which are changeable to enable them to adapt (soft adaptation) to a change. Designs of such buildings are called soft designs, in contrast to hard designs which create an inflexible spatial configuration (Kinnane et al., 2016). Flexible buildings can be moveable or extendable, have adjustable facades or layouts, parts that are removable or replaceable, and reusable materials. A rating scale was used to measure the flexibility: poor flexibility representing buildings which have one or no components which are flexible to allow the building to adapt to effects of climate change such as overheating and flooding. Average flexibility representing buildings with two flexible components; and good flexibility representing buildings with a diversity of components that allow the building to adapt to climate change. The flexible components were recorded before rating the flexibility.

Results show the unavailability of space that allows buildings to be extended (Figure 6.14). This also reduces the space between buildings, impacting on ventilation, which is vital for free flow of air to cool the settlement. Only 16% of the houses have expansion space in their backyard or front yard.

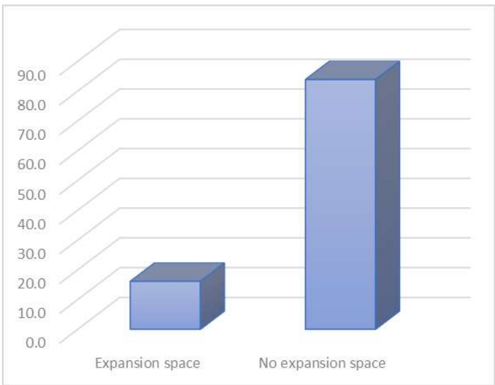


Figure 6.14. Expansion space at Msunduza

In rating the buildings, generally most buildings were found to have poor flexibility. When viewing flexibility against a building type, it was mainly the kiosks, marketplace, and workshops which demonstrated average to good flexibility (Figure 6.15).

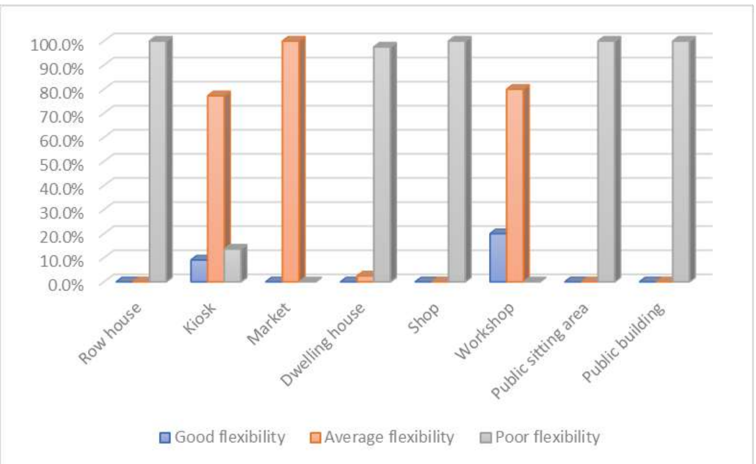


Figure 6.15. Results of flexibility against building type

When assessing flexibility against materials, the results show that buildings which are flexible are those that use metal sheets, wood, and bamboo as walls (Figure 6.16). These materials clearly are easily removable and replaceable without changing the whole of the building. Some of these buildings are moveable and could be relocated to a different place in the case of unbearable climate conditions.

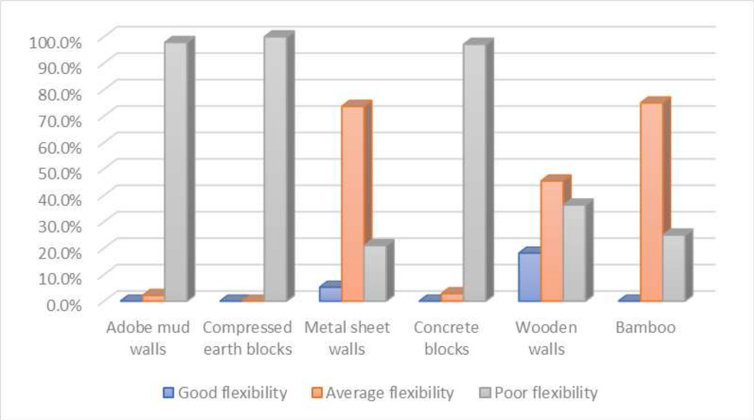


Figure 6.16. Results of flexibility against material use

The spatial distribution of the buildings is presented in Figure 6.17. Buildings with poor flexibility are spread across the whole settlement. Buildings with average and good flexibility are mostly concentrated centrally in the settlement. This is the densest area, hence there is a lot of economic activity which uses the more temporary buildings which are more flexible in design.

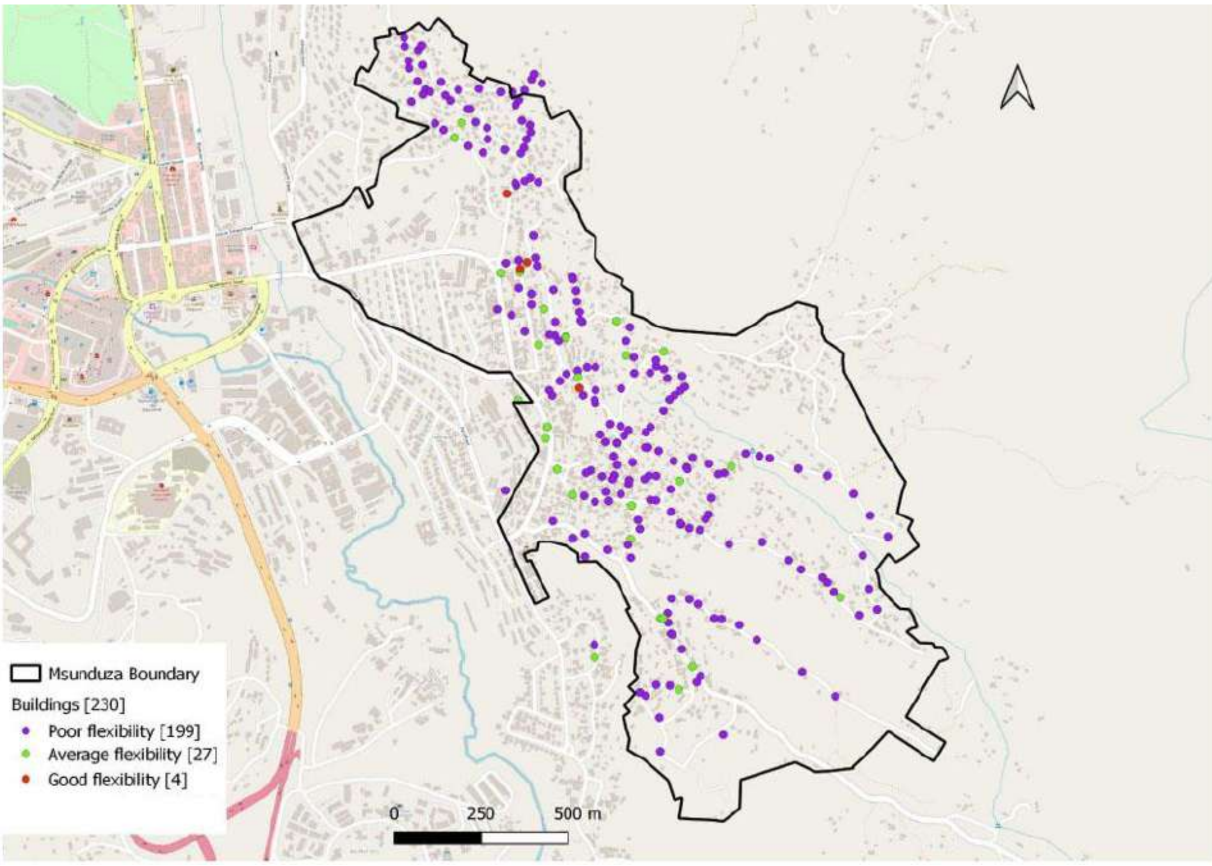


Figure 6.17. Spatial distribution of flexibility of buildings

It can be concluded that the temporary buildings are more flexible in design and have potential to adapt easily to climate change when compared to the more formal and permanent buildings which use concrete blocks as building material. The formal buildings tend to have fixed elements which are not moveable or reusable, reducing their adaptability.

6.4.2.4. Building services (energy)

At settlement level it was observed that energy supply is centralised and sourced from fossil fuels. Energy sources at building level (lower scale), within the boundaries of each household, were also assessed. The aim of this assessment was to determine response diversity of energy supply within the premises of the building, and further to verify if the buildings connect to the central public energy supply from the Eswatini Electricity Company.

The results showed no other alternative energy supply. Most of the buildings connect to public electricity (Figure 6.18). Even though the public electricity network reaches all parts of the settlement, the results show that 18% of households do not connect to this network possibly due to unaffordability. Such households are believed to use firewood for energy. Some structures for commercial purposes (11%) have no energy supply.

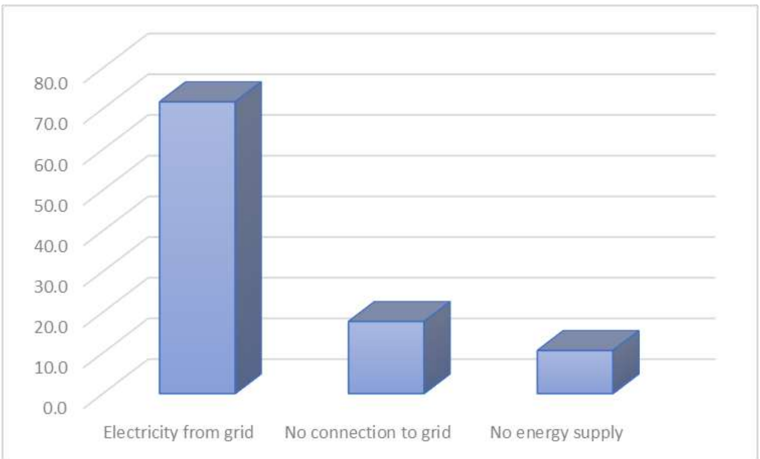


Figure 6.18. Energy supply chart

It can be concluded that there is no response diversity in energy supply, not only at the settlement level but also at building level. This means the whole settlement is vulnerable to climate effects, as a failure of the central energy supply will affect all households since there are no other energy sources that address energy supply. Alternative energy sources such as renewable sources need to be introduced to improve resilience of the energy supply systems to climate change effects.

6.4.2.5. Building services (water supply)

Water supply systems were also assessed at building level to determine redundancy of water supply systems. In the case of drought for instance, dams (source of public water) may dry off, but with the availability of water harvesting tanks and communal boreholes, the residents can survive through that affected period. The availability of alternative water supply systems provides redundancy and therefore resilience of the water supply systems. Water supply systems that were sought include water tanks for water harvesting, boreholes, and whether the houses connect to the public water supply identified at settlement level.

Results show no alternative water supply systems. Most of the buildings at Msunduza receive water from the centralised public water supply system which draws water from the Hawane Dam. There is an opportunity of harvesting water from roofs, but most households do not have water tanks, possibly due to affordability issues. Results show 69% of buildings connect to the public water supply system (Figure 6.19). The remaining are believed to source water from natural streams or get water from neighbours who have a connection to the public system. Shops and kiosks also do not have any constant water supply, possibly since it is not much of a requirement in those buildings, and such buildings comprise 13% of the sample. Water may be provided using small containers for cleaning or as required.

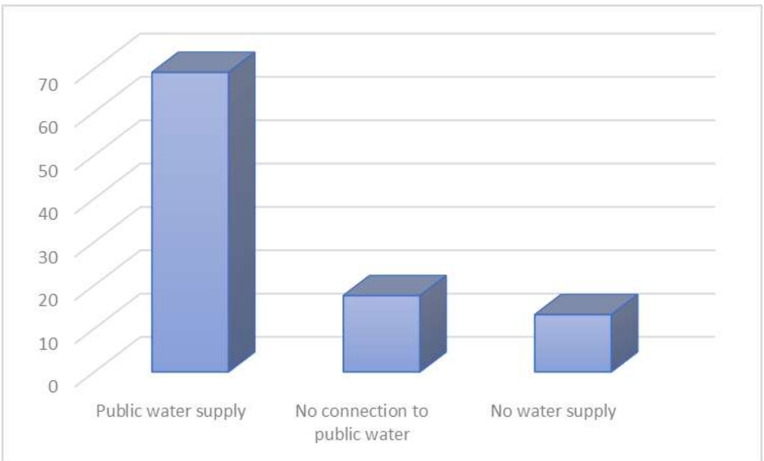


Figure 6.19. Water supply chart

It can be concluded that there is no redundancy in water supply systems both at settlement and building levels. This shows vulnerability of the water supply systems to climate change effects that may target these systems. Lack of an alternative system results in a water supply system with low adaptive capacity. Alternative and affordable water collection and storage systems should be introduced to improve resilience of these systems.

6.4.2.6. Building site (Storm water and windstorms)

Storm water management systems within the site can be addressed through, for example, water harvesting, storm drains, and vegetation (green infrastructure). Windstorms, on the other hand, can be addressed by vegetation or fences to reduce the wind pressure, use of steep roofs rather than flat steel roofs, as well as overall building form which allows wind to move through. The site of each household was therefore assessed to determine its potential to address storm water as well as windstorms.

Adaptive capacity of the storm water management systems within the site was determined through assessing diversity of the storm water management systems such as storm drains, green cover and water harvesting systems. Results in the previous sections show that water harvesting is not practised as water harvesting tanks were not observed in the yards of the sampled homes. As much as this area is on a steep slope, storm drain channels were also not observed within the house yards but were only observed along some of the main roads and along some of the footpaths. What was identified to address storm water within the household premises was the green cover in some of the homes, however, not as much as it was observed at settlement level. In the absence of other storm water management systems, the type of vegetation was assessed in detail and the following vegetation was identified: small plants only (in 34% of the homes), grass cover only (18%), and hedge only (4%). In some homes a mix of vegetation was identified - plants, hedge and grass cover (7%), and another mix was plants and grass (3%). In 35% of homes the yard was bare, with no vegetation at all. This information is presented in Figure 6.20.

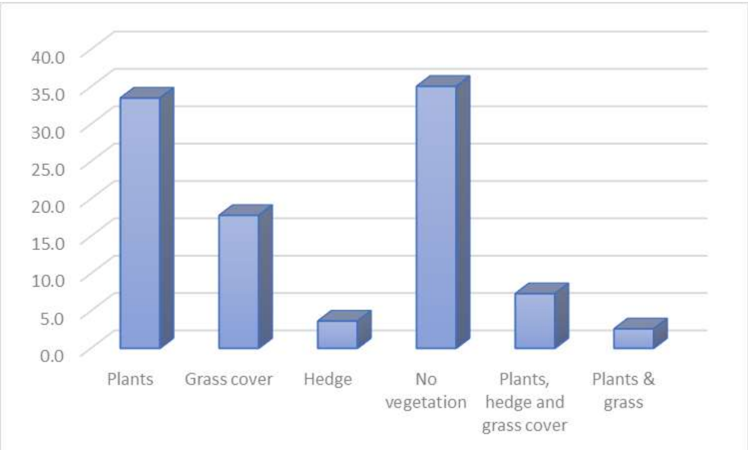


Figure 6.20. Vegetation cover within house premises at Msunduza

The results generally show minimum diversity in storm water management systems within the home premises which may result in runoffs causing erosion or affecting residents. Water may collect in areas which have a potential of spreading mosquitoes and diseases.

With regards to wind management, most households (73%) have grown trees surrounding the houses which can break wind pressure. However, most roof designs are flat metal sheets exposed to wind, with only 6.6% of houses having parapet walls. Buildings with steep roofs comprise only 9.1% of the houses at Msunduza. The information is presented in the chart in Figure 6.21 below.

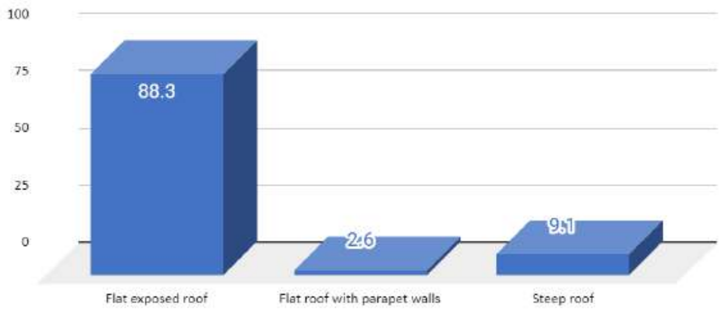


Figure 6.21. Results on roof type at Msunduza

It can be concluded that storm water is addressed by vegetation, and there are no other water management systems, which makes the buildings vulnerable to flooding. The sites further address wind pressure effects through the dense fruit trees in most households, as well as steep roofs and parapet walls in about 12% of the buildings in the settlement. This however shows poor resilience to the effects of strong winds and flooding.

6.4.3. Resources

Resources, according to Peres (2016), refer to the components of the city which regenerate, renew, and provide the life force of the city. According to the author this includes leftover spaces around buildings, public open spaces, and private yards holding potential and resources for natural and social exchange. In this study we assessed the functional groups of green networks, food systems, and waste disposal believed to sustain life in the settlement. The aim was to determine their resilience to climate change so that strategies for developing their adaptive capacity can be proposed where there was a need.

6.4.3.1. Green networks

The green networks provide essential ecosystem services to urban areas. Informal settlements are exposed to a variety of ecosystem disservices because of their location and climate variability (Dodman, Kibona & Kiluma, 2011). It is vital for dwellers of these settlements to appreciate and have access to ecosystem services for the benefits listed by Chapin and Tilman (2006): 'shelter, fresh water, food, biomass production, nutrient cycling and water cycling.' For ecosystems to continue providing those services, conserving them may not be enough to sustain them, but systems around them should also promote their health and evolution so that they are beneficial even to future generations. Ecosystem services further support the economy and livelihoods of residents (Cohen-Shacham et al., 2016; Lafortezza & Chen, 2016; Maes et al., 2016) and, more recently, is being used to address increasing societal challenges (e.g. climate change, food security, or economic competitiveness).

The adaptive capacity of green networks, therefore, needs to be assessed and addressed, if necessary, to sustain and promote biodiversity, avoid habitat fragmentation, and sustain ecosystem services to ensure livelihoods of residents is sustained, among other benefits.

Green networks were assessed at Msunduza to identify what constitutes green networks and how they are distributed on the site. Vegetation, as discussed in earlier sections, was identified through satellite imagery by calculating the NDVI through a software called QGIS. An evaluation was conducted by identifying the point where everything above 0.26 represents vegetation. The surface area of this vegetation was calculated. Further to that, the natural streams and wetlands were also identified through satellite imagery as well. These components (green networks) are presented through a map as shown in Figure 6.22.

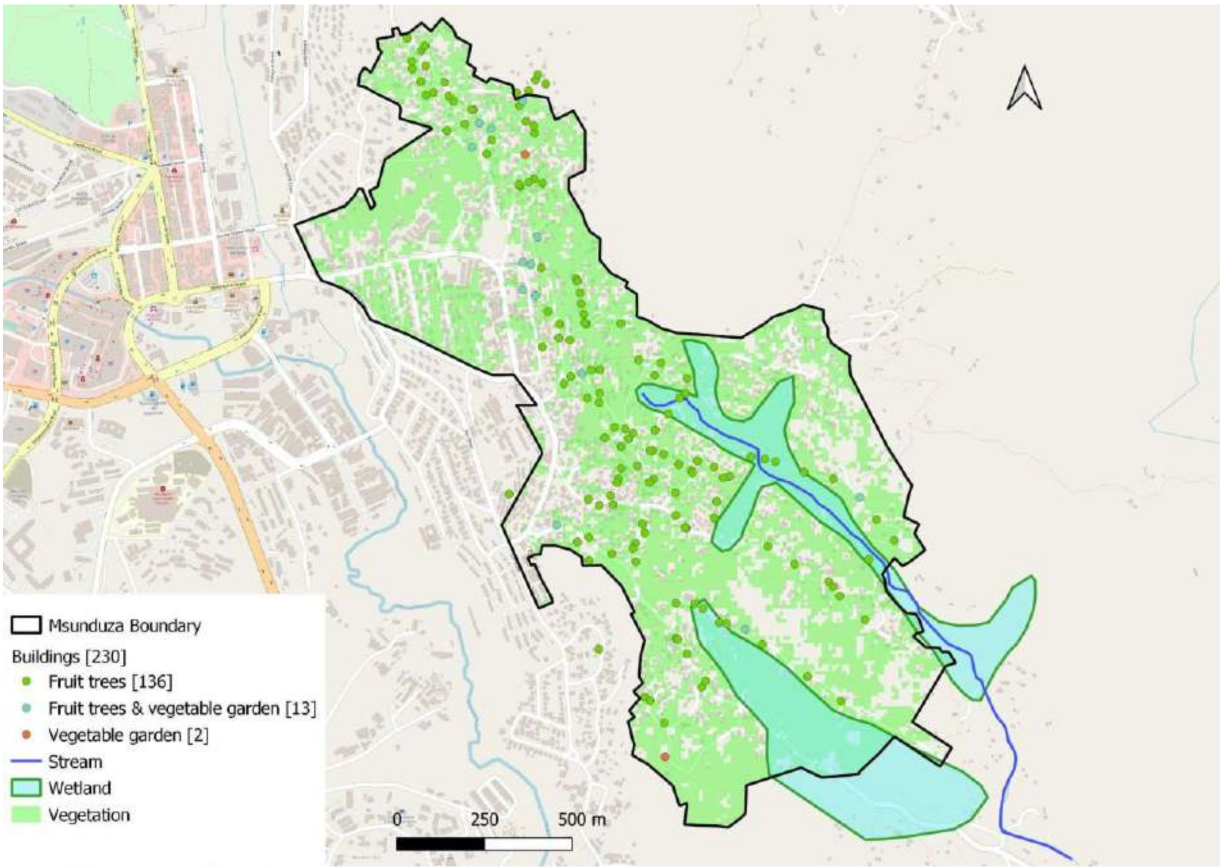


Figure 6.22. Spatial distribution of green networks at Msunduza

Vegetation was observed to be covering a better part of Msunduza possibly due to the fruit trees that were observed in most homesteads. The kind of vegetation identified include the fruit trees within homestead premises, plants along streets and undeveloped land, and vegetable gardens within homesteads. However, it was observed that the biodiversity was under threat due to the densification of the settlement and wetlands currently serving as dumping sites in some areas, which further pollutes the rivers cutting across these wetlands.

6.4.3.2. Food systems

Urban food issues are very critical and should be addressed as well. Urban food is important as it contributes to the reduction of poverty. This aligns with the Sustainable Urban Development Goals. Hallegatte (2016) states that by 2050 over "two thirds of the world's population are destined to live and eat in urban areas". This puts pressure on food systems that require cities to work towards meeting the demands of the rapidly urbanising areas. When addressing food related issues such as food security, the focus is normally on agricultural production. Other critical issues that should be addressed include reduction of food lost or wasted, and the prevalence of obesity and undernourishment common in poor communities such as informal settlements are also critical issues which should be addressed.

Modern food systems consist of retail shops and fast-food stores. On the other hand, traditional systems include family run retail stores and informal systems common even in the informal settlements. Informal systems include the street foods which the urban poor rely on. In this study food systems identified relate to agricultural production as well as retail. Fruit trees were observed in 73% of the households and vegetable gardens in 12% of the households. In 25% of the households there was no form of food production observed. There is only one big central marketplace in this area where vegetables, fruits, and other food are sold. Shops comprise 5.7% of the buildings, and kiosks 9.6% of the buildings. This information is presented in the chart in Figure 6.23 below.

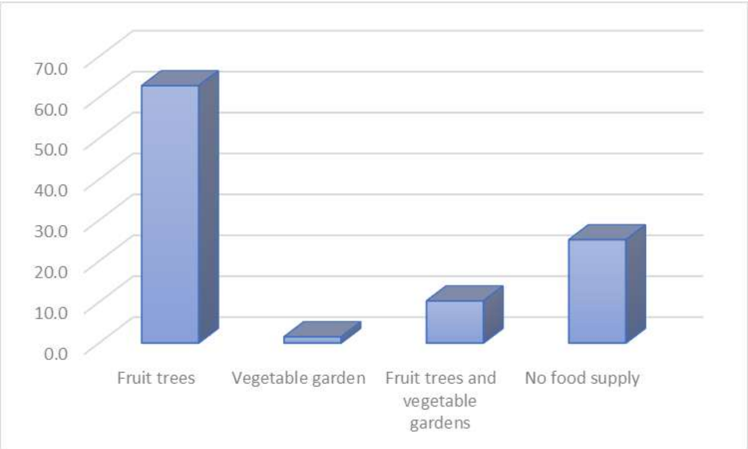


Figure 6.23. Food production at Msunduza

A map was further produced to show the distribution of the food systems as shown in Figure 6.24. The expectation would be that there would be practices of agricultural production along the stream as common practice in Eswatini, however it is not the case. Vegetable gardens were found mainly in fenced households. Most households are not fenced in this area and probably that is the main reason the residents do not practise agriculture. Vegetables that are sold in the kiosks and marketplace are clearly sourced outside the settlement.

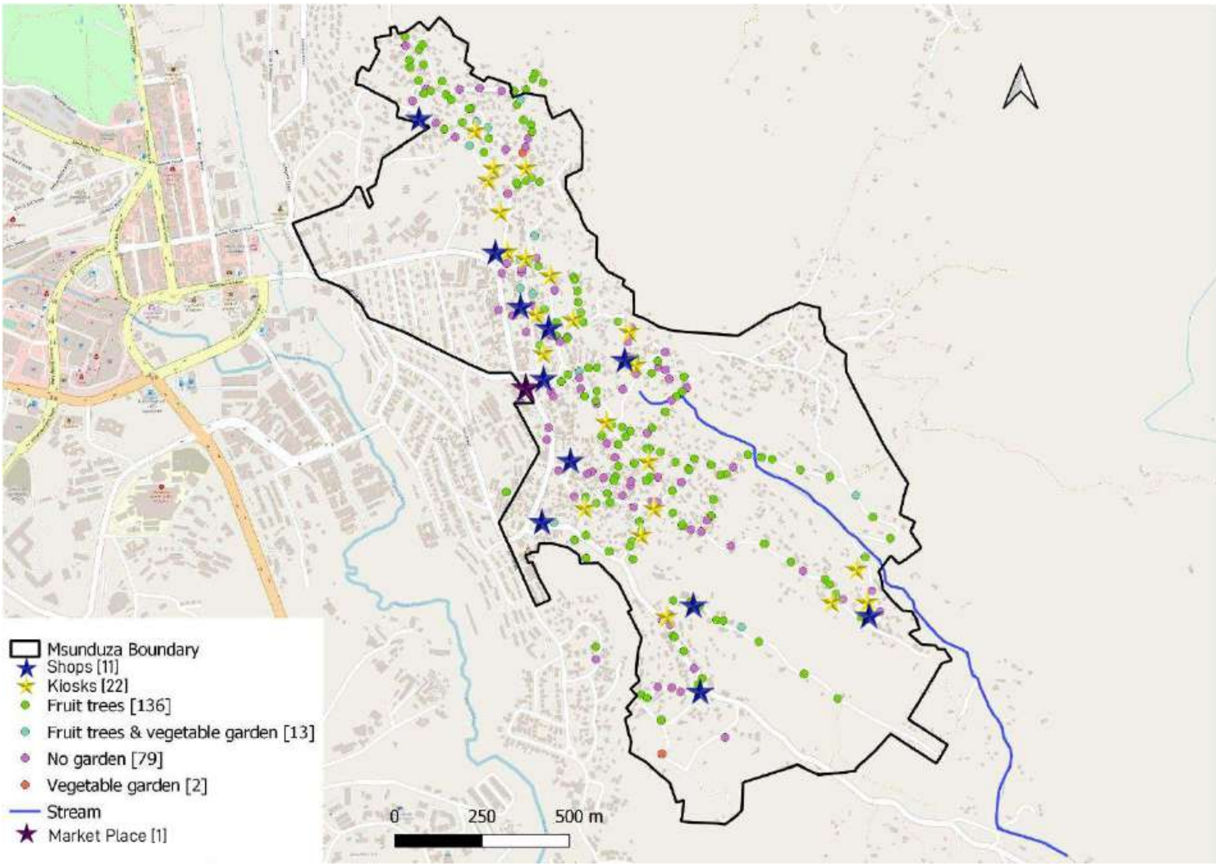


Figure 6.24. Food systems at Msunduza

The figure above presents the same information spatially through a map. It is evident that there are no agricultural practices along the streams.

6.4.4.3. Waste disposal

Waste management is another area that requires attention when addressing climate change. Solid waste is a huge contributor to GHG emissions through decomposition of organic matter especially in unregulated dumping of waste (Gautam & Agrawal, 2021). Food waste, in these dump sites degrades and creates methane. Unregulated landfills further release leachate or contaminated water that enters rivers, groundwater and soil. This has an impact on wildlife, marine life and people that live near or work on the dumpsites (Gautam & Agrawal, 2021). In Msunduza it has been observed that areas closer to dumpsites also experience loss of biodiversity. Natural habitats are replaced by waste and animals ingest waste littered along streets and in unregulated landfills. Sustainable collection is a need in such areas to manage the impacts of waste to the natural environment. Six Municipal dumpsites (Figure 6.25) were identified across Msunduza.

Figure 6.25. Dumpster used at Msunduza

A map was produced to show their distribution across the Msunduza area. Figure 6.26 shows a radius of 100 metres around each dumpster with a walking return distance of roughly 2 minutes at Msunduza. If it is considered that residents can walk for a 1 minute to dump waste and walk back home for another minute, then the non-highlighted areas in the map on Figure 6.26 can be considered vulnerable. Residents might find walking longer distances an inconvenience and opt to throw waste in streets, storm drains and unregulated landfills. This makes the settlement unsightly and leads to flooding, air and water pollution, and spread of diseases and other health problems. These challenges, as observed at Msunduza, are very common in informal settlements.

It can be concluded that there is low response diversity in terms of waste management. This leaves a better part of the area at risk of waste impacts which further affects the adaptive capacity of the settlement to the impacts of climate change. For instance, the absence of a dumpster leads to residents throwing waste to drains, which further blocks them and reduces their functionality in addressing flooding/runoffs. That leaves the area vulnerable to flooding.

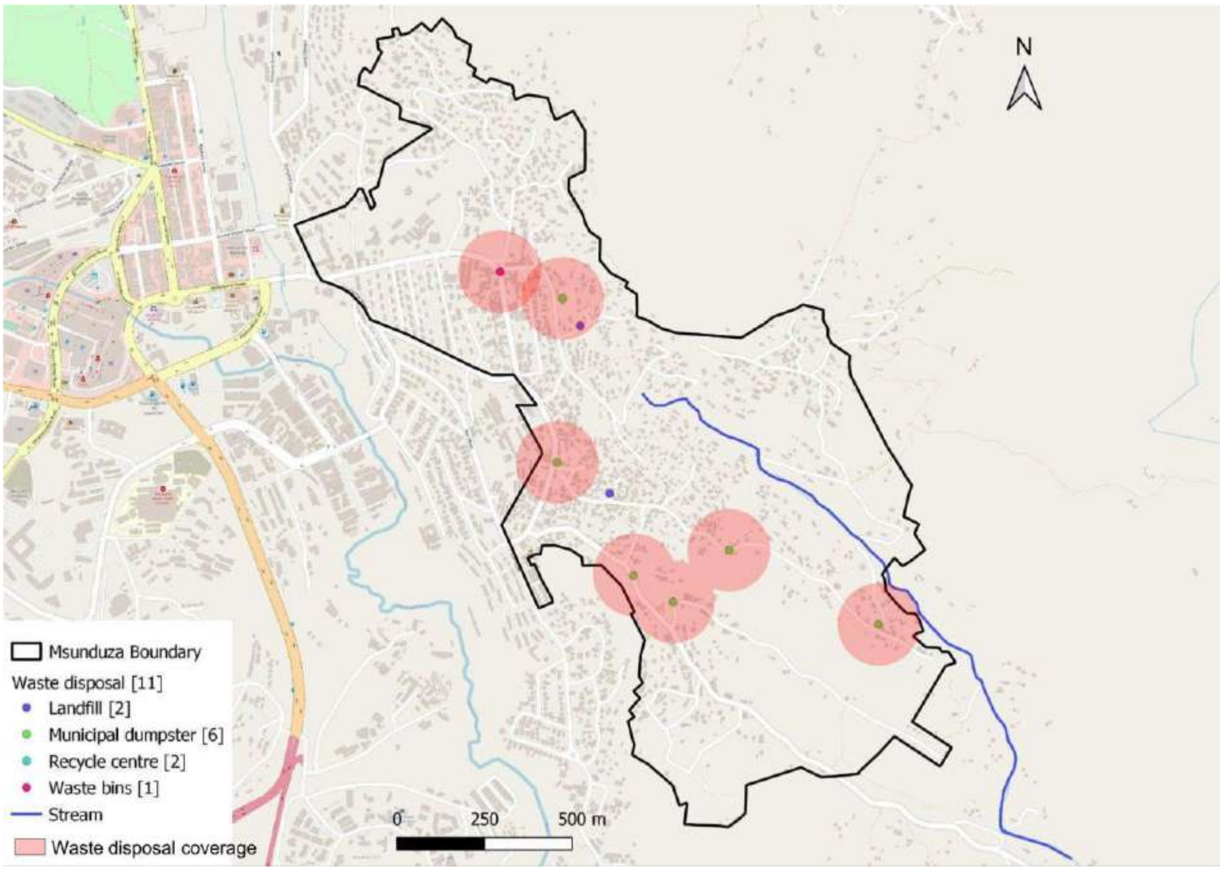


Figure 6.26. Spatial distribution of waste management systems (dumpsters) at Msunduza

The residents and stakeholders of Msunduza can effectively tackle the waste management problem by regarding waste as a resource. Learning from other cities is key.

6.5. Discussion

The adaptive capacity of Msunduza is understood as the combination of the adaptive capacities of the subsystems of the settlement which are responsible for keeping the settlement functional by ensuring sustainability of the valued attributes of the settlement such as health, safety, movement, clean water supply, energy supply, food security, and waste disposal. Such subsystems are categorised under infrastructure, building, and resources which comprise the physical dimension of a settlement.

The resilience of an informal settlement is heavily affected by changes in systems outside the boundaries of that informal settlement. For instance, the rapid growth of urbanisation at city scale from the independence of 1968 to date, put pressure on natural systems of informal settlements resulting in a decline of their resilience. Also changes at building scale, which in most cases are not regulated, has an effect in the resilience at settlement scale. The dynamics and interaction between the different scales result in a high dynamic resilience. This is witnessed at the current reorganisation phase of the settlement driven by the urban development program. The installation of infrastructure such as the storm drains has improved the resilience to flooding in portions of the settlement which have been upgraded, and the parts of the settlement where the storm drains were not installed, have low adaptive capacity to flooding. This has resulted in different adaptive capacities in different parts of the same informal settlement, Msunduza.

The following subsections discuss the results about the resilience of infrastructure, buildings, and resources.

6.5.1. Infrastructure

The adaptive capacity of the infrastructure varies from component to component and from area to area within the settlement, however, generally the resilience of infrastructure is low. The resilience applicable to infrastructure is engineering resilience, which absorbs disturbance to continue providing the necessary service and adjusts the system back to its original state after a disturbance. The assessment was therefore assessing the capacity of infrastructure to withstand flooding, extreme heat, and storms through backup systems, diversity of responses, and connectivity.

Water management systems generally have a low adaptive capacity as a result of the lack of diverse water management systems to reduce run-offs that eventually affect houses and residents of such areas. Resilience of these systems continues to decline as building density and population growth increases in such areas because of people searching for affordable housing and services. This affects the natural means of managing storm water through the decline in green cover and increases the blockage of storm drains by waste. It is an expectation that as the human population grows, waste will also increase resulting in more storm drain blockages due to poor waste management which has been observed. It was observed however that most of the area is covered with vegetation mainly because of a possible tree planting project that was done in the past, and the fact that the site is in a region that receives the highest rainfall when compared to other regions of the country of Eswatini. Since Msunduza sits on a mountain, rainwater flows at high speeds, causing the flood impact to be more intense, hence the high numbers of buildings washed away by floods in such areas, as reported by the National Disaster Management Agency (2015). An approach to adaptation would therefore include increasing the capacity of storm drains and installing them across the whole settlement, improving waste management and encouraging green cover that can absorb and reduce the flow speed of runoffs.

With regards to extreme heat, the settlement adapts well on the southern part since there is a mix of vegetation, wetlands, and a natural stream. The vegetation, especially trees, provides shade to residences along streets and within building yards. Wetlands and natural streams cool the surrounding areas through evaporation of the water surface. The top part of this settlement however has poor response diversity to extreme heat and therefore low adaptive capacity. The affordable way of managing heat could be through natural means. However, it is also critical to manage waste even for this part to ensure maximum evaporation that cools the surrounding areas. Solid waste has been observed to float and cover the water surfaces, reducing the water surface for evaporation.

Water supply and energy systems have centralised systems with no response diversity nor backup systems. This results in systems that are vulnerable to sudden dramatic changes (Walker & Salt, 2006). The drought of 2015 affected the function of water supply such that water was rationed as the centralised source of water was drying up. With regards to energy, the situation is even worse as 70% of energy is imported from South Africa. That country is currently struggling with generating capacity to meet its own needs, resulting in planned rotating blackouts (a practice referred to as load shedding). This reduced supply has already impacted Eswatini and mostly the informal settlements. The price of electricity has been continuously going up as the demand increased. Alternative water supply systems and energy systems to create redundancy should be considered to maintain the functions of energy and water supply in these settlements. This, however, could be possible through a subsidy to decrease the costs of backup systems which residents may not afford.

There are no telecommunication systems except for the mobile phone towers. The monthly service fees of telecommunication systems may prove to be expensive for residents of informal settlements even though they would increase the adaptive capacity of communication systems. In the absence of a network, calling for assistance in the case of a disturbance or emergency may be a challenge. Movement systems do not represent a well-connected internal layout of vehicular roads and pedestrian paths and they are further limited to a few access points in a broader scale. Such challenges also limit the response speed of climate affected areas such as power outages or emergencies from flooding. In the case of a recent uprising in Eswatini where roads were blocked, it became evident that the movement networks play a huge role in the function of a settlement.

6.5.2. Buildings

Poulsen et al. (2020) state that significant efforts have been made on climate mitigation in the building sector but there is less focus on buildings adapting to climate change. The impacts of climate change in an informal settlement are more severe in buildings because of the poor-quality material used. Infrastructure within informal settlements is normally developed and funded by the government, such as the case in Eswatini, yet when it comes to buildings, they are self-built by residents without any professional guidance. The 'building' component of the settlement is therefore very important to manage.

The adaptive capacity of buildings to the impacts of climate change at Msunduza is also generally low. There is however a variety in building typology and building material use in this settlement. There is diversity in building typology, however most of the buildings are standalone units, and most of the structures are built of concrete blocks with metal roofs as building material.

Heat adaptation of buildings was rated, and the marketplace, public sitting area, and a percentage of kiosks were the only structures which had traces of good adaptation. A majority of the typologies have poor adaptation, meaning they have one or no component of the building which responds to overheating. This means the dwelling units, where residents spend most of their time, put residents at risk of heat stress, sick building syndrome, and poor comfort, and these risks increase as average temperatures increase. Material use and ventilation systems need to be properly used to increase the resilience of these buildings to heat impacts.

The building services, which normally connect to services at larger scales, do not include backup systems even at building level. These are normally cross scale systems which can still be addressed even at building scale and contribute to the resilience at neighbourhood scale. Energy for example is drawn from the grid which is a centralised energy supply system. Renewable energy sources such as small-scale photovoltaic cells can contribute to resilience of energy systems at building scale. At the current state, households do not have alternative energy supply systems that could be used while the main energy supply system is being restored after a disaster.

Buildings also rely on the main public water supply system for access to clean water. There are no alternative water supply systems at building level which can sustain the function of water supply in case the public system is affected by disturbances related to climate change. Water harvesting technologies can be sufficient in creating the adaptive capacity of water supply systems. Storm water, on the other hand, is addressed mainly through vegetation, and there are no other water management systems. The lack of other storm water management components makes the buildings vulnerable to flooding. Since the settlement sits on a hill, however, the water does not necessarily accumulate in one area and rise to flood buildings. The main issue is the pressure of the flow which damages or washes away weak buildings. Wind pressure is also addressed by vegetation within the premises of each homestead. Affordable facade technologies or design features that can redirect wind can prove helpful to reduce risks from storms.

6.5.3. Resources

The adaptive capacity of resources, such as green networks, food systems, and waste disposal, is under threat. The increase in population and structures puts more pressure on green networks, which affects ecosystems. Extreme temperatures and unpredictable rainfall are a risk to ecosystem services, which can eventually affect the economy and livelihood of the residents. Green networks have already been discussed in previous sections to include fruit trees in most homesteads, plants along streets, a few vegetable gardens within homesteads, wetlands, and a natural stream. As much as trees dominate this network, biodiversity can still be improved.

Food systems are critical in these areas occupied by the urban poor (Bredenoord, 2016). Improved food systems can reduce poverty, which is basically the main sustainable goal in developing these areas. Food systems relate to agriculture in small scale and retail which are more dominant. Kiosks are scattered across the settlement, as well as a few shops and a central vegetable marketplace. Based on the few local agricultural initiatives, supplies of the kiosks and marketplace are mainly imported from outside the settlement. Empowerment to produce local food is required to improve the food system in this area.

Waste disposal is one of the major challenges not only in this informal settlement, but also most informal settlements globally. Besides being a contributor to GHG emissions, solid waste also pollutes the natural environment, affects biodiversity, and blocks storm drains, which are all important in addressing climate change effects. Dumpsters were located in a few areas across the settlement; however, these central waste disposal systems are not easily reachable by many residents, who then opt to dispose of waste in storm drains and water systems. The low response diversity of waste management can be improved through diversifying these systems and further investigating waste recycling and using some of the solid waste for agricultural purposes.

Table 6.6 below presents a summary of the findings on the current adaptive capacity of the informal settlement, Msunduza, which was notably changing with the adaptive cycle. The vulnerable and resilient components of Msunduza are presented through rating the adaptive capacity of each component expected to respond to climate change effects. The findings are linked with findings from the previous chapter which identified the climatic risks. This chapter explored the vulnerability of the selected informal settlement to the impacts of climate change. The structure of the table is also transferred to the next chapters.

Table 6.6. Adaptive capacity status of Msunduza

1] Risks	Valued attributes	Component	2] Adaptive Capacity Status/ Vulnerability
Infrastructure Impacts	Clean water	Water management systems	**Poor**: Centralised water supply system with no response diversity/backup systems **Poor**: Lack of alternative water management systems to reduce run-offs. **Average**: Green infrastructure
	Energy	Energy supply systems	**Poor:** Centralised energy system with no response diversity/backup systems
	Communication	Communication systems	**Poor**: Mobile communication system only
	Movement	Roads and footpaths	**Poor**: Poor connection of road and footpath network. Few access points leading to poor modularity.
	Wellbeing [health]	Heat management systems	**Average:** The southern part of the settlement has a mix of vegetation, wetlands and a natural stream. The northern part has poor response diversity to extreme heat.
Building Impacts	Comfort and wellbeing	Heat management systems	**Average:** Market place, public sitting area and kiosks have good adaptation to extreme heat. A majority of typologies have poor adaptation - one or no component responding to overheating.
		Water management systems	**Poor:** No on-site measures to manage storm water run-off
	Safety	Wind management systems	**Poor**: windbreak provided by trees. Buildings do not adapt to strong winds.
	Affordability	Material (There are surely other things affecting affordability which are outside the scope of the study)	**Average:** Diversity of building material, however concrete blocks with metal roofs dominate.
	Clean water	Water supply systems	**Non**: No backup systems and few houses with water collection systems
	Energy	Energy supply systems	**Non**: No backup systems
Environmental impacts	Ecosystem services and Biodiversity	Green networks	**Average**: High coverage of vegetation. Wetlands and streams identified; however, ecosystems are under threat due to densification and pollution
	Food	Food systems	**Poor**: A minority has vegetable gardens, and a majority with fruit trees Few shops and kiosks identified
	Waste disposal	Waste management systems	**Poor**: Sparse distribution of dumpsters Informal unregulated landfills

6.6. Conclusion

The aim of this chapter is to present results of the fieldwork conducted at Msunduza to address the objective: *to assess the current adaptive capacity of informal settlements to climate change*. Preceding the fieldwork was a description of the study area that unpacked the main issues of concern, identified components (subsystems) which should be assessed, and disturbances to which the components should adapt, defined the spatial scale of the focal system, and discussed the systems above the focal system and how they shaped the focal system. Further to that, a discussion on previous dynamics of the focal system was conducted to determine how the system has changed over time. Understanding how the study area arrived at its current condition, as observed through the fieldwork, provided a comprehensive basis for the study.

Informal settlements are poorly prepared for climate change making them vulnerable to flooding and landslides as a result of poor-quality buildings and lack of infrastructure to address flooding and withstand heavy storms and also adapt to heat waves (Revi et al., 2014). Eswatini shares the same challenges in the informal settlements which are claimed to be vulnerable to the impacts of climate change. The effects experienced by informal settlements and upgrading areas in Eswatini, which are also considered as the issues of concern, include infrastructure effects, environmental effects and building effects. As confirmed by the experts interviewed, these effects are specifically caused by extreme heat, intense rainfall or flooding, drought, and storms.

To address the effects of climate change on informal settlements, Msunduza, located in Mbabane, Eswatini, was selected for the study. This focal system was formed and shaped mainly by historical and political systems. When observing the historical timeline of this settlement, the restrictions to live in towns led to the formation of temporal structures at the outskirts of the town forming Msunduza informal settlement. Other political events such as independence in 1968, led to the growth of Msunduza due to the influx of businesses which demanded more labourers. The dynamics of the informal settlement shows the settlement shifting from one phase to another and it is currently claimed to be at the reorganisation phase where infrastructure has been partially installed and formalisation is ongoing.

The resilience of the settlement was determined through an assessment of components under the three functional groups of the settlement, namely infrastructure, building, and resources. These can also be understood as subsystems of the settlement. The results show that the settlement poorly adapted to extreme heat, with the low diversity of heat management systems in infrastructure and building. Fruit trees found across the whole settlement contribute to the provision of shade from extreme heat. However, this may not be enough, and the increase in urbanisation continues to put pressure on these trees and other vegetation that improves cooling of these areas. Passive ventilation practices in buildings are not efficiently employed, possibly due to lack of knowledge and guidance. The southern part of Msunduza has been observed to be well adapted to extreme heat at settlement level as a result of the combination of natural streams and wetlands which provide cooling through evaporation, and the green cover which traps heat and further provides shelter.

With regards to flood management, the settlement generally has a low capacity to adapt. This is blamed on solid waste which blocks storm water drainage, lack of storm water drainage in a larger portion of the settlement, rigidity of buildings, and generally lack of diversity of water management systems. The dominant green cover, however, contributes to water absorption, but since the settlement sits on a slope, water flows through the vegetation cover. The poor adaptive capacity to flooding has led to houses being washed away and structural damages to buildings and impacts on the road system.

The settlement further has a low adaptive capacity to storms, but the trees also play a major role in breaking wind speed. Residents need to be educated about building and orientation of buildings to adapt to strong winds. Since wind changes are not monitored in Eswatini, it becomes a challenge to plan for a working intervention that can increase the adaptive capacity of the settlement to strong winds.

Generally, the results show that Msunduza informal settlement has a low adaptive capacity to the impacts of climate change; however, there are traces of good adaptation which can be enhanced. The identified vulnerable areas provide useful insights for identifying the strategies that will be proposed for guidance increasing the adaptive capacity of informal settlements through the self-help housing development and upgrading programmes. The following chapter presents findings from a study of precedents that have addressed similar challenges posed by vulnerabilities as identified in this chapter.

Chapter 7: Overview of approaches to climate change adaptation

7.1. Introduction

The resilience of urban areas, especially in underdeveloped regions such as those in southern Africa, is questionable and requires enhancement (Ndebele-Murisa et al., 2020). Eswatini urban environments, as discovered in the previous chapter, are exposed to harsh weather, climate variability, and extreme climate events among other risks associated with climate change. Literature (Adger et al., 2005; Dhar & Khirfan, 2017; Friend & Moench, 2013; IPCC, 2014; Pelling, 2011; Peres, 2016) suggests that climate change is unavoidable and therefore requires our neighbourhoods to adapt to the impacts/effects of climatic change to ensure these areas continue to function and provide necessary services for the survival of the residents.

Learning is essential to enable proper design of future neighbourhoods and retrofitting the current neighbourhoods to adapt to current and future climate changes. To learn from other developments and ideas that have addressed similar challenges, this chapter profiles different approaches to addressing climate change disturbances. Based on results from Chapter 5 which show that low-cost housing and neighbourhoods are more vulnerable to climate change, and Chapter 6 which presents the vulnerability of informal settlements to climate change, this chapter only focuses on solutions that have the potential of working in such contexts. Precedents are presented with the aim to investigate how other projects have addressed adaptation of neighbourhoods and buildings to climate change disturbances like those experienced in Eswatini as discussed in the previous chapter, with the intention of meeting certain urban sustainability goals. Precedents presented are those addressing overheating, flooding, drought, and increased wind load and related effects on neighbourhoods (buildings, infrastructure and resources).

Precedents were selected from a collection of climate responsive projects documented in Clegg and Sandeman (2019). This document was purposely selected for study mainly because it already has a collection of climate responsive design strategies in developing countries, uses affordable building technologies, is available publicly, projects have been reviewed in a conference, projects are in a similar context as the study area, and the document was known and readily available to the researcher.

A conference conducted in Kampala, Uganda, on 27 and 28 February 2019 on 'Raising Awareness for Climate Responsive Design in East Africa', resulted in the development of The Manifesto for Climate Responsive Design. This conference was organised by the Belgian NGO, ENABEL, which later published the document in both hard copy and soft copy format downloadable from their website[1]. The manifesto looks at how architecture can respond to the environmental challenges faced by East African countries. It is focused on the climate and cultural context of East Africa and presents case studies from Uganda, Rwanda, the DRC, and Malawi. The document gives a set of climate responsive design solutions that have been applied in the rural areas of East Africa, which the study reviews to understand their application and further determine solutions that can be incorporated in the context of this study. The principles used are applicable in different climatic contexts globally (Clegg & Sandeman, 2019). The resilience of the case studies is assessed, and opportunities are captured to inform the design strategies of informal settlements to climate change proposed in the next chapter.

As the manifesto project designs focused more on addressing extreme heat impacts, additional precedents were purposely selected after a Google search using search terms such as 'climate responsive designs', 'climate responsive projects', and 'projects adapting to climate change'. Google search was preferred since it provided grey literature, such as reports, which discussed the projects in depth. There was, however, a high possibility of missing many qualifying precedents due to the assumed high volume of projects addressing climate related issues as these may not have been discoverable using the above search terms or are not presented on the internet. However, the intention of this search was not to find all existing or proposed solutions, but to get a sense of the approach to the development of strategies that are implemented to ensure resilience of buildings, infrastructure, and resources. Any effective strategy was considered and explored for consideration in the development of design strategies for informal settlements in the context of Eswatini.

A small sample size was considered to increase the depth of the analysis. Purposive sampling ensured the selection of 'information rich' precedents which meet the criteria of: climate responsive design, applicability in informal settlements in the context of Eswatini, designs responding to the identified climate change risks in residential settlements of Eswatini, and precedents with detailed information about their context. Despite the sample which could be considered low, saturation was reached early in the analysis due to the similar method of using green technologies to address climate change impacts as discussed in the following sections.

[1] https://www.feildenfoundation.org.uk/manifesto-for-climate-responsive-de

The discussion below is grouped into two categories: review of precedents in the African context, and review of precedents outside Africa. The results were compared with suggestions from interviewed experts in Chapter 5.

7.2. Precedent Study Overview (Clegg & Sandeman, 2019)

The projects purposely selected using the defined criteria above are presented in Table 7.1. The sections that follow discuss each precedent in detail and identify technologies implemented to increase the adaptive capacity of the precedents.

Table 7.1. Selected precedents for assessment

	Case study	Location	Risks addressed
1	COF Outreach Village Schools	Villages in Rakai and Lwengo, Uganda	Extreme heat impacts
2	Rugerero Health Centre	Rubavu District, Rwanda	Extreme heat impacts Storm impacts
3	Ilima Primary School	Ilima Village, Republic of Congo	Extreme heat impacts Flooding impacts
4	National Teachers' College, Kaliro	Kaliro, Uganda	Extreme heat impacts Flooding impacts Drought impacts
5	Lake Bunyonyi Vocational Secondary School	Lake Bunyonyi, Uganda	Extreme heat impacts Flooding impacts Drought impacts
6	Early Childhood Development and Family Centres	15 Districts, Rwanda	Extreme heat impacts Drought impacts
7	Ruhehe Primary School	Musanze, Rwanda	Extreme heat impacts Drought impacts
8	Rwamagana Leaders' School Dormitory	Rwamagana District, Rwanda	Extreme heat impacts
9	AWF Primary Schools	Karamoja, Uganda	Extreme heat impacts Drought impacts
10	Mzuzu University Health Centre	15 Districts, Rwanda	Extreme heat impacts
11	Nakapiripirit Vocational Institute	Karamoja, Uganda	Extreme heat impacts Drought impacts

7.2.1. COF Outreach Village Schools

Cotton On Foundation, a non-profit organisation from Australia, approached Studio FH Architects to develop a set of typical primary school designs to be constructed on different sites in Uganda (Figure 7.1). The requirements were for the designs to be able to adapt to many different sites, meaning they had to be independent of their orientation to the site. The schools had to accommodate 500 pupils and ten teachers, the latter residing on site. Seven schools were eventually constructed and three were still under construction by 2019 (Clegg & Sandeman, 2019). A summary of the project is presented in Table 7.2 below.

Figure 7.1. Site layout of one of the COF Outreach Village Schools (Localworks, 2015)

Table 7.2. COF Outreach Village Schools project description

Architect	Studio FH Architects
Location	Villages in Rakai and Lwengo, Uganda
Client	Cotton on Foundation
Area	Approx. 1500 sqm
Year	2015 – 2020

Following the brief, the architect designed the schools to have five main classroom blocks with toilets, a kitchen block, as well as teachers' accommodation (Figure 7.2). One of the classrooms consists of a multipurpose space positioned in between two classrooms to be used as a dining space and assembly hall. These school designs are part of a list of designs considered to be climate responsive in the Manifesto. An analysis of the design, however, shows the design to be mainly responsive to extreme heat.

As a response to increasing temperatures, the schools (classroom blocks) consist of covered walkways on all sides of the buildings (Figure 7.2) to keep the walls cool and to enable the typical designs to adapt to different sites. Other passive design principles implemented include silver reflective roofing material which limits thermal transfer of solar radiation to the classroom space below. All windows are under shade and the design allows for cross, as well as stack ventilation. The classrooms further have ventilation panels on the roof. The good passive ventilation is also enabled by the shallow building depths and upward movement of air. There are also high-level perforations, which allows heat to escape through night flushing. Trees are also planted around the buildings to provide shading to the facades of these buildings.

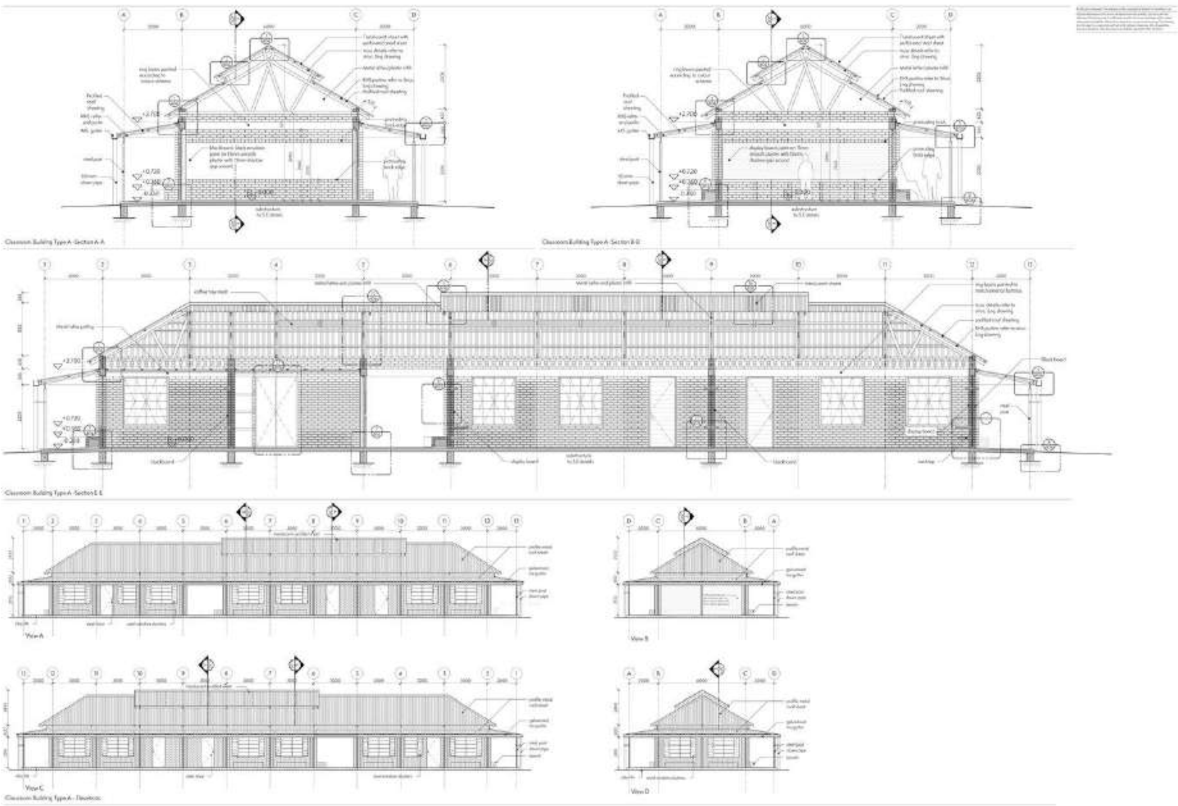


Figure 7.2. Cross sections and elevations of COF classrooms (Localworks, 2015)

The design further addresses adaptation of the energy generation systems with the use of biogas which supplements electricity from the grid. The stoves used for cooking utilise both the gas from biodigester toilets and traditional timber fuel if required. Energy use is reduced by distributing the big windows evenly to allow an even distribution of daylight. Windows are also fitted with shutters to regulate access of daylight depending on the need. The buildings are covered with roof sheets which are perforated to allow access of daylight even on cloudy days, which reduces the use of energy. The perforation of roof coverings would be a challenge in a rainy climate.

Sustainable methods of managing solid waste were implemented, including the use of bio-latrine which has a biodigester that supplies gas to the kitchen. The teachers' toilets also stand on top of septic tanks (aqua privy), which reduces the use of water in the toilets. Other useful technologies include water harvesting systems in some of the buildings, which also provides an alternative to water supply in the school. Table 6.3 below captures a summary of information relevant to climate adaptation to learn from.

Table 7.3. Climate adaptation principles implemented in the COF Outreach Village schools

	Overheating	Flooding	Storms	Drought
Building	-shaded walls and windows -reflective roofing -perforated roofing -shallow building depth and opposite windows -wall perforations -shutters on windows			-water harvesting
Infrastructure	-planting trees		-biogas from biodigester toilets and traditional timber supplement electricity from the grid	
Resources				-toilets on top of septic tanks (aqua-privy) to reduce water use

It can be concluded that the focus of this precedent is on green building principles rather than designing for adaptation to climate change. This can be considered the goal of the project. The classrooms were designed to respond to extreme heat hence a diversity of cooling systems that were implemented. There is also a diversity of energy systems which supplement each other. This means should one energy generation system be affected by the effects of climate change, there is another that may keep functioning. There is no mention of wind adaptation of buildings, however the use of wooden louvres to cover windows also blocks strong wind from affecting the internal space of the building. The incorporation of trees in the site design may further assist in breaking strong winds.

7.2.2. Rugerero Health Centre

Rugerero Health Centre was designed by ASA Studio architects to improve health services and services approximately 45 000 people living in Rugerero Sector and surrounding rural areas in Western Uganda (Clegg & Sandeman, 2019). The health centre project was initiated by Health Builders, and it was partially financed by the local government with the aim to provide a high-quality health facility. The locals participated in design and construction of the health centre using locally available materials and traditional technologies to build the centre.

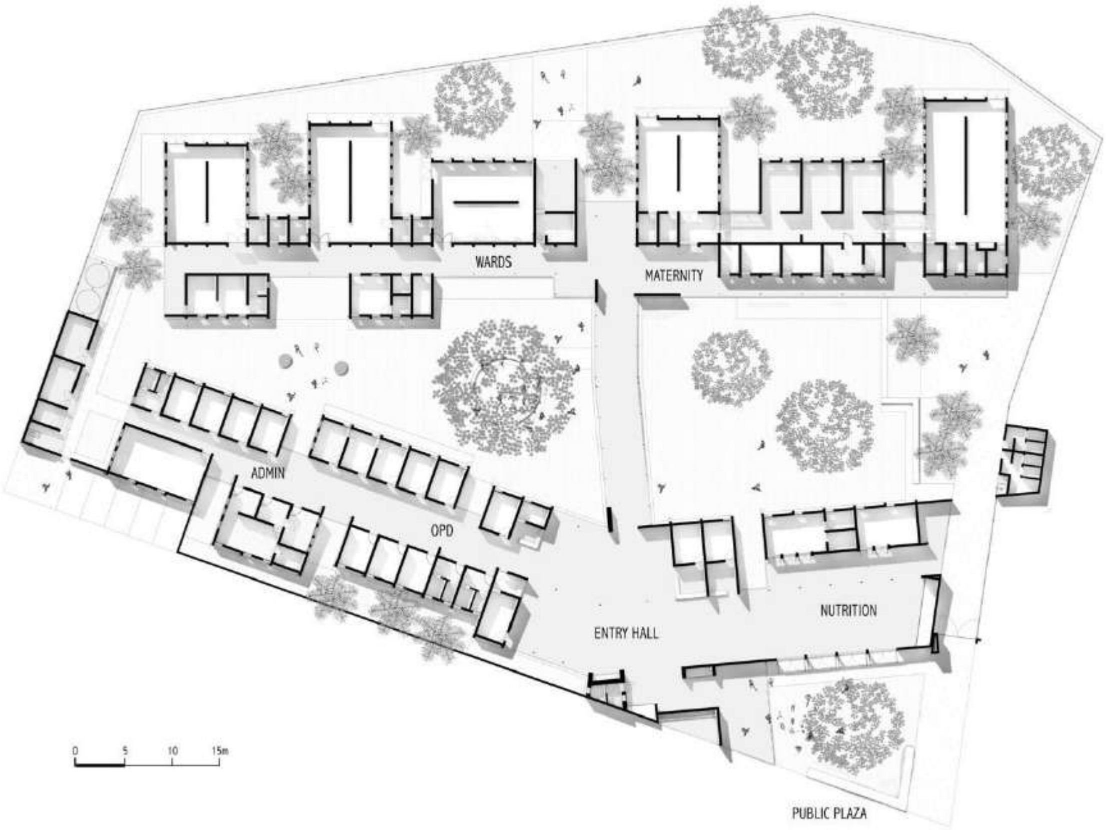


Figure 7.3. Rugerero Health Centre layout (ASA Studio, 2017)

The project consists of two blocks which are connected by a central corridor with the first block comprising reception space, waiting areas, outpatient department, nutrition and administration space as shown in Figure 7.3 above. The other block consists of the wards and maternity unit. There is also a separate block which consists of an incinerator, generator, storage, and water treatment. Table 7.4 presents a summarised description of this precedent.

Table 7.4. Rugerero Health Centre project description

Architect	ASA Studio
Location	Rugerero Sector, Rubavu District, Rwanda
Client	Health Builders and Rubavu District
Area	2800 sqm
Project period	2017-2018

This precedent also has a focus mostly on addressing extreme heat, energy consumption, and sustainability principles, which are vital in addressing climate change impacts. The design consists of green patios which contain different species of trees and shrubs with the aim to reduce local temperatures through evaporative cooling. At the same time this is used to provide a healing environment for the patients. This building also has large overhangs around the courtyard which keep direct sunlight off the walls. To provide further cooling, a double skin roof was developed. Timber with damp proof and insect preservative was used as a ceiling material for this facility. This ceiling is attached to wooden purlins underneath the steel trusses, creating an air gap which prevents thermal transfer from the metal sheets.

Energy consumption is also addressed by introducing natural light, especially in consultation rooms, wards and the delivery area. The layout has cut-outs to allow daylight into the internal spaces. To maximise daylight, the design includes feature windows, wall perforations, and roof lights. Shading devices and woven screens are used to control intense direct light. Table 7.5 captures vital information for consideration in the development of climate resilient buildings. The table (and all other similar tables that will follow) only captures technologies that contribute to climate adaptation of buildings, infrastructure and resources.

Table 7.5. Climate adaptation principles implemented in the Rugerero health centre

	Overheating	**Flooding**	**Storms**	**Drought**
Building	-cut-outs in walls -damp proof ceiling -double skin roof -green patios -large overhangs -shading devices and woven screening			
Infrastructure				
Resources				

In terms of addressing climate change impacts, this design also focuses on extreme heat, with no solutions for flooding and storms. Overheating is well addressed, and the building can be deemed resilient to overheating, considering the diversity of cooling systems, as discussed in the paragraphs above.

7.2.3. Ilima Primary School

Ilima is a remote Congolese village located in the jungle of the Congo Basin, about six hours by motorcycle from the nearest airstrip. The African Wildlife Foundation (AWF), a non-profit organisation, approached MASS Design group (architects) to design and build Ilima Primary School (Figure 7.4) in this remote area. Andrew Brose, the MASS group director based in Kigali, Rwanda, temporarily relocated to Ilima with his family to lead the construction. Table 7.6 presents a summarised description of the precedent.

Figure 7.4. Ilima Primary School aerial view (MASS Design Group, 2016)

Table 7.6. Project description of Ilima Primary School

Architect	MASS Design Group
Location	Ilima Village, Republic of Congo
Client	African Wildlife Foundation
Area	800 sqm (building) and 1100 sqm (plot)
Project period	2012 – 2015

The primary school is claimed to be the largest and most complex structure in that region, with a capacity of 350. Its site (Figure 7.5) was planned by staking two circles, one for a demonstration and conservation garden, and the other for a play area for the children. The building sits between the two circles and its form was created by the two arcs that face away from each other.

The southern arc contains three classrooms and a library, and the northern arc has three classrooms and an administration space. The two arcs are connected by a suspended canopy roof. Besides being a school, the building also serves as a community centre.

The school was clearly designed with sustainability in mind which, at the same time, made the school climate resilient, especially to overheating. The school is claimed to be a building with zero embodied energy and has been designed for extreme sustainability addressing the role of architecture in limited-resource conditions. Building materials used were almost all locally available, with 99% of the materials sourced from within 10 km of the site.

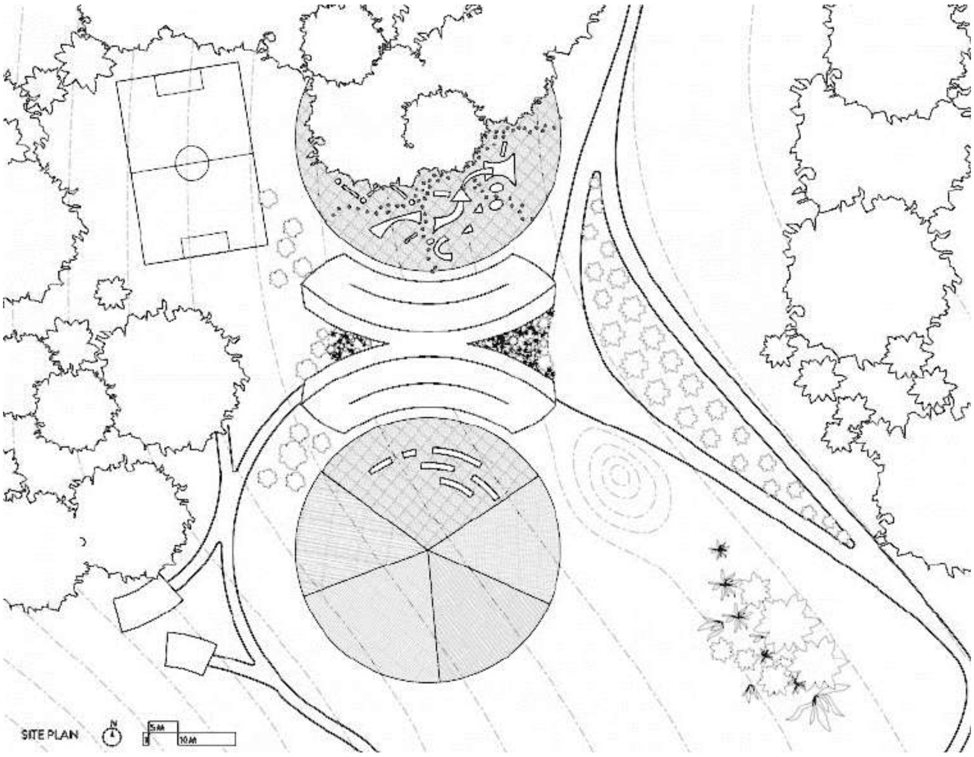


Figure 7.5. Ilima Primary School's site layout (MASS Design Group, 2016)

The materials used included sun-dried adobe brick for the walls. These walls were plastered with clay-sand mix, white clay, and boiled palm oil. The palm oil makes the bricks more resistant to water. The roof structure used timber (Lifake tropical hardwood trusses and roof framing) from local trees which were hand-sawn, planed into proper hardwood trusses, roof framing, furniture, and all architectural details. The trees used were identified within 6 km of the site and the wood did not require any treatment as it is good for external use. For roof coverings, wood shingles were used and they were formed from local trees. Wood shingles were chosen over metal roofs since the former is easy to replace and maintain, whereas metal sheets have to be bought from somewhere else. This wood shingles innovation is claimed to be repeated in several local houses creating a local economy for the area. Finally, the doors were made from Lifake hardwood frames with a peeled Liliann vine weaving that was dried before its use to avoid shrinking.

The sun appears to the south from October to March, and to the north from April to September, so the building was oriented on the east-west axis to maximise solar shading, and the building form (arc) responds directly to the local sun path. This orientation ensures that classrooms remain completely shaded throughout the whole year. Further, the building has extra-large overhangs to shield the classrooms and common areas from the sun.

According to MASS group, the building is designed with an open clerestory to accommodate the hot climate with no mechanical ventilation. Internal walls do not go up to the ceiling but reach two thirds of the ceiling height to ensure unrestricted airflow encouraging natural ventilation and daylight to make the classrooms comfortable. There are high level horizontal vents in the roof to allow hot rising air to escape through stack ventilation. The windows and doors are perforated and pivot to allow free airflow and light even when closed during bad weather.

Figure 7.6. Classroom with perforated doors and windows (MASS Design Group, 2016)

The climate of the Congo being hot and humid as a result of its location on the equator, the Ilima primary school was designed to adapt to extreme heat through the use of local materials which do not conduct heat. The use of local materials ensures a quick response to rebuilding of a structure after being affected by climate-related disruptions. This precedent further presents information on how to use affordable building technologies which is critical in informal settlements. Other strategies applied included the use of solar shading methods, and passive ventilation. As much as this building adapts more to overheating, there are also heavy rainfall adaptation methods implemented, as the roof has a steep roof with gutter systems to respond to very heavy rainfall.

The table (Table 7.7) below presents some of the identified strategies used to make the building adapt to climate change.

Table 7.7. Identified climate change solutions at Ilima Primary School

	Overheating	Flooding	Storms	Drought
Building	-use of high thermal mass local materials (sun-dried adobe brick) -orientation to east-west axis -building form responds to sun movement -extra-large overhangs - open clerestory to accommodate the hot climate -internal walls do not go up to ceiling height -roof vents -perforated doors and windows	-plaster made of clay-sand mix with clay and boiled palm oil -steep roof with gutter systems		
Infrastructure				
Resources				

7.2.4. National Teachers' College, Kaliro

The National Teachers' College (NTC) is a secondary teaching training centre designed by FBW Group following the dilapidation of the former structures. The client for this project was the Ministry of Education with a vision of providing quality and effective education. The architects' design provided sufficient learning space, addressed function, energy needs, and a suitable learning space. The attempt was to 'strike a balance between analysis, context and beauty'. The summarised description of the project is presented in Table 7.8 below.

Table 7.8. National Teachers' College Project Description

Architect	FBW Group
Location	Kaliro, Uganda
Client	MoES Uganda and Enabel
Area	615 sqm (typical classroom block)
Project period	2014

The NTC campus consists of a library, classrooms, workshops, laboratories, administration offices, student accommodation, and teaching buildings. The buildings designed by FBW Group are narrow and have a mono pitch roof. They are oriented along the east-west axis with vegetation surrounding the buildings.

Figure 7.7. National Teachers' College (FBW Group, 2014)

This precedent also partially addresses climate change impacts, with the focus being on overheating. The buildings are designed to keep the classrooms comfortable. They have exaggerated roof overhangs to provide shading from direct sunlight and reduce solar gain of the brick walls. The spaces have ventilated roof cavities to prevent transfer of thermal heat from the metal roof sheets, and there are suspended plastered ceilings in each room. Further, for solar protection, the buildings have been oriented along the east-west axis. The classrooms have opposite windows on the north and south facades ensuring cross ventilation. Solar chimneys have also been included in the design to improve ventilation. Solar chimneys draw hot air from interior spaces and transport it out of the building. Lastly, to improve cooling, the design has a double door where the interior door is fitted with burglar bars and a mosquito net, and the other outer door consists of glass. This allows the outer door to be left open during hot nights to allow hot air to escape the building.

In terms of water management, water is supplied from rainwater harvesting, boreholes, water reservoirs and an underground water pump. The large surface area of the monopitch roof captures large volumes of water which flows to the gutters positioned at the lower edge of the roof. The rainwater is channelled to two large plastic tanks at the ends of each building. A 100 000-litre steel water tank is also positioned on the site.

Sustainable waste management technologies have been implemented such as the biodigester. The sludge is collected and used for fertiliser, while liquid waste drains into a reed bed. The gas created is used for cooking in the kitchen. There are also big storm water drainage channels which channel water down to nearby reservoirs. The vegetation on the site also addresses runoffs through infiltration. Table 7.9 below captures and summarises important climate resilient technologies that have been implemented in the design.

Table 7.9. Climate Adaptation technologies implemented in the NTC

	Overheating	**Flooding**	**Storms**	**Drought**
Building	-narrow buildings -orientation on east-west axis large overhangs -ventilated roof cavities -suspended plastered ceilings -cross ventilation - solar chimney -double door (burglar and mosquito net for internal panel)			
Infrastructure	-underground water pumps	-big storm water drainage channels -water reservoirs -vegetation -reed bed for wastewater		-rainwater harvesting, boreholes, water reservoirs,
Resources				

Diversity of heat management systems is observed in the campus design, making these systems adaptable to extreme heat. The existence of water harvesting technologies, boreholes, reservoirs and underground water pumps, also enables the water supply systems to survive in the case of drought and improves the adaptive capacity of the water supply system. The trees on the site break strong winds, however there are no other alternative means of addressing strong winds, making the development vulnerable to strong winds. The risk of flooding is addressed by storm drainage channels and vegetation on the site. The extended roof overhangs also prevent water from affecting the building. The precedent can be considered resilient to flooding to some extent and fully resilient to extreme heat.

7.2.5. Lake Bunyonyi Vocational Secondary School

Lake Bunyonyi Secondary School is a vocational boarding school designed by the Feilden Foundation and FCB Studios. The site layout of the school is presented in Figure 7.8 below, and a description of the school is presented in the following paragraphs.

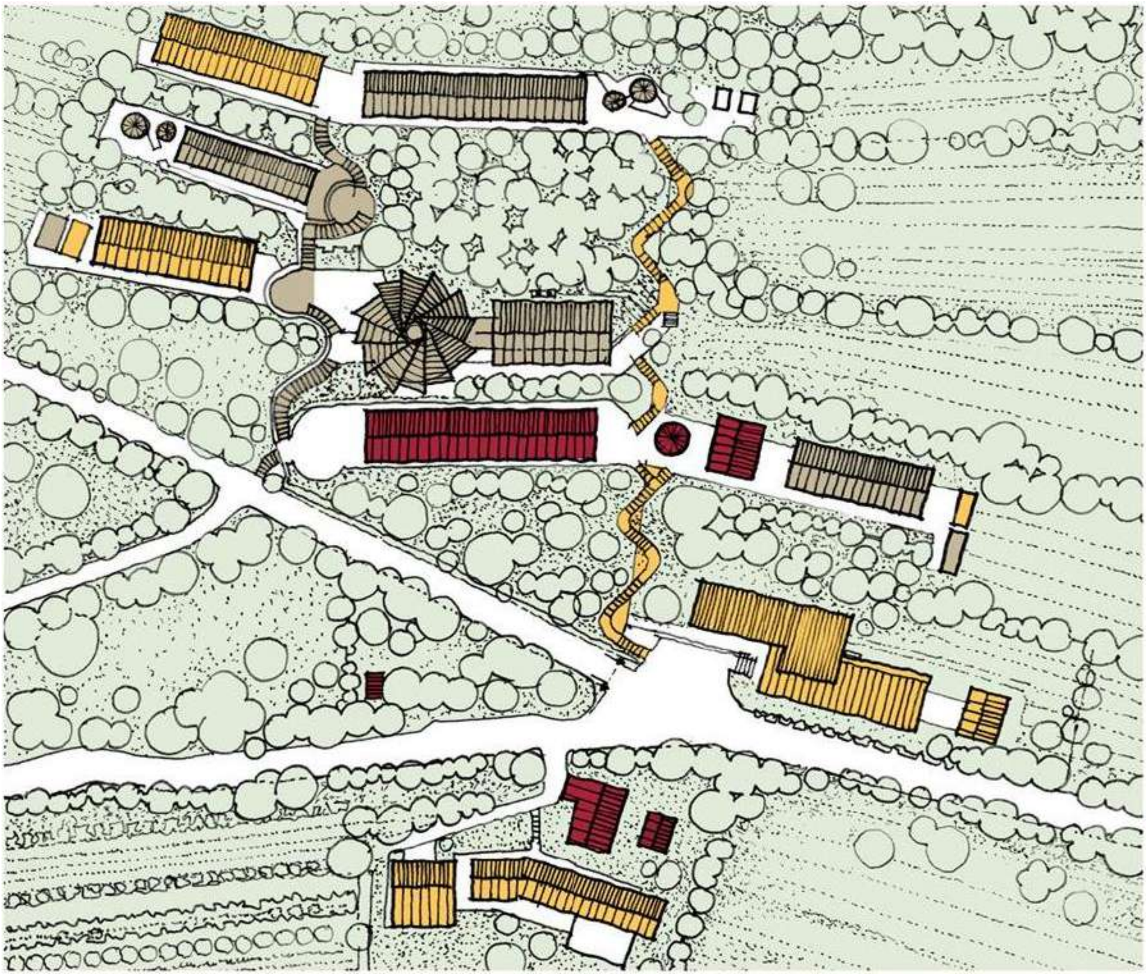


Figure 7.8. Site plan of Bunyonyi Vocational Secondary School (FCB Studio, 2006)

The school sits on a steep slope at the edge of Lake Bunyonyi. It has developed incrementally from a single classroom in 2007 to a school for more than 300 children by 2019 (Clegg & Sandeman, 2019). Pathways had to be created up and down the slope while avoiding the possibility of erosion (Figure 7.8). The design consists of buildings positioned along the contour lines connected by stairways and pathways. There is a circular structure which has a dining area space and school communal activities. A kitchen is built adjacent to this structure and there is a two-storey dormitory and classroom block which has been recently built. The summarised project description is given in the table below.

Table 7.10. Lake Bunyonyi Vocational Secondary School project description

Architect	Feilden Foundation/ FCBStudio
Location	Lake Bunyonyl, Uganda
Client	Lake Bunyonyi Christian Community Vocation Secondary School
Area	Not given
Project period	2008 - present (2019)

To address climate change impacts, this project addresses water management. Every building has a tank for collecting rainwater to reduce runoffs and further provide water for washing and cooking. A storm water drainage channel was established on the site to deal with excessive runoffs on rainy days. This drainage channel was built out of bricks to slow the flow of water. It discharges water into a long swale closer to the entrance road of the site.

This development further promotes agriculture to keep a constant food supply. The school produces its own food such as beans and cabbages to reduce operational costs. Beekeeping is also practised, and the produce meets the demand in the school such that the excess product is sold to the public for additional income.

Natural light is allowed evenly into the buildings through the large, evenly distributed windows on both sides of the classrooms. This also creates cross ventilation to cool these spaces. The windows have wooden shutters to control the quantity of light, depending on the need at that time. Using sustainable local materials and local labour reduced the costs of construction. Since material is readily available close by, it makes buildings easily reconstructed should they be destroyed by the impacts of climate change.

Table 7.11. Climate Adaptation technologies implemented at Lake Bunyonyi School

	Overheating	**Flooding**	**Storms**	**Drought**
Building	-opposite windows -windows with wooden shutters -local materials	-water tank		-water tank
Infrastructure	-local materials	-storm water drainage channel built of bricks -long swale		
Resources				-agriculture (beans and cabbages) -bee keeping

This development has traces of adaptation strategies to extreme heat, and flooding but there is no mention of adaptation to strong wind. The table above captures the climate adaptation strategies used in this campus.

7.2.6. Early Childhood Development and Family Centres

The early childhood development and family centres have been implemented in 15 districts across Rwanda for the purpose of empowering the communities and families. These projects, designed by ASA Studio for UNICEF Rwanda, were required to adapt to different sites (topographical and geological conditions) so that they can be replicated. Below is a table with a summarised project description.

Table 7.12. Early Childhood Development and Family Centres project description

Architect	ASA Studio
Location	15 districts in Rwanda
Client	UNICEF Rwanda
Area	500 sqm
Project period	2013 – 2016

In response to the requirement of a replicable design, ASA Studio designed a modular system with components that adapt to different terrains and situations and come together to create similar facilities positioned around a common gathering space. The design comprises a group of buildings which are connected by a roof and walkways creating a central courtyard (Figure 7.9). The composition includes the stimulation room, multipurpose hall, open demonstration kitchen, administration block, and sanitation facilities.

Figure 7.9. Early Childhood Development and Family Centres (ASA Studio, 2013)

In the assessment of climate change resilience of this precedent, it was observed that this development addresses water management to adapt to changes in climate. These centres aim to be water self-sufficient therefore a 35 000-litre tank has been installed underground in all the centres to ensure sufficient supply of water. The tank is made of masonry brick, and it has a reinforced concrete foundation. All the clay tile roofs comprising 500 square metres collect water which is harvested using gutters and downpipes connecting to the water tank. This water source is accessible not only by the occupants of this development but also residents that live close to this centre.

Further to that, waste is managed sustainably using ecological sanitation technology which diverts urine from faeces so that this is eventually used for agriculture. Liquid waste is diverted to a tank and eventually used for irrigation, and the solid waste is mixed with water and eventually used as fertiliser for crops.

In terms of cooling the building, the buildings have multiple perforations in the walls, which provide passive ventilation and natural lighting. These perforations are placed strategically according to the prevailing wind patterns to avoid wind and driving rain from entering the interior of the buildings. The perforations allow cool air to circulate through the building at night to cool the building from the built-up heat gathered by the masonry walls during the day. Table 7.13 below presents the results of the assessment of this precedent.

Table 7.13. Climate Adaptation technologies implemented in the Early Childhood Development and Family Centres

	Overheating	**Flooding**	**Storms**	**Drought**
Building	-modular systems -perforations on walls			
Infrastructure	-trees	-ecological sanitation technology -water tank		-35k litre water tank
Resources				-liquid waste is diverted to tanks and used for irrigation -solid waste is mixed with water and used as fertiliser for crops

The analysis of this precedent shows that this development partially adapts to climate change. The big water storage tank, filled through water harvesting, may supply water in times of drought. The waste management system, which uses wastewater for irrigation, also ensures consistent food supply and further reduces water consumption for agricultural purposes. Extreme heat is also addressed in this development, mainly through the multiple perforations which provide passive ventilation. There are also a few trees which contribute to the cooling of the buildings. Natural lighting is allowed into the building through the perforations. The absence of alternative systems, however, makes the components less resilient and more vulnerable to climate change effects. In all the technologies implemented, there seems to be a lack of diversity and lack of backup systems to ensure resilience of this development, even when affected by the impacts of climate change.

7.2.7. Ruhehe Primary School

The Ruhehe Primary School was designed by African Design Centre fellows under MASS Design Group to serve 1 120 students from pre-primary to the sixth grade. This was a redesign of an already existing school that lacked the appropriate infrastructure to support its growth. It was designed following lessons learnt from a pilot project of Mubuga Primary School. A summarised description of the project is presented in Table 7.14 below.

Table 7.14. Ruhehe Primary School project description

Architect	MASS Design Group; African Design Centre
Location	Musanze, Rwanda
Client	M2 Foundation
Area	560 sqm (building) and 12 000qsm site
Project period	2018

The ADC fellows managed to come up with a community centred design emphasising capacity building at all stages. The aim of this development was to improve learner outcomes, increase satisfaction among students and teachers, and increase student retention rates through improved design. The newly constructed buildings have five classrooms, a library, headmaster's office, and administration facilities. Two existing classrooms were refurbished. The new design also incorporated designated playscapes and a community plaza.

In this project skylights were used to ensure adequate daylighting, and direct sun and glare is eliminated by decorated light shelves hung below the ceilings. Locally sourced materials were used in this development and the community participated in the sourcing of the material within 50 km of the site, fabrication of material, and construction. The sustainable material used for the structures help in keeping a comfortable learning environment and reduced the response time in the case the building needs to be adjusted to improve its adaptive capacity to extreme heat Results of the assessment are shown in Table 7.15 below.

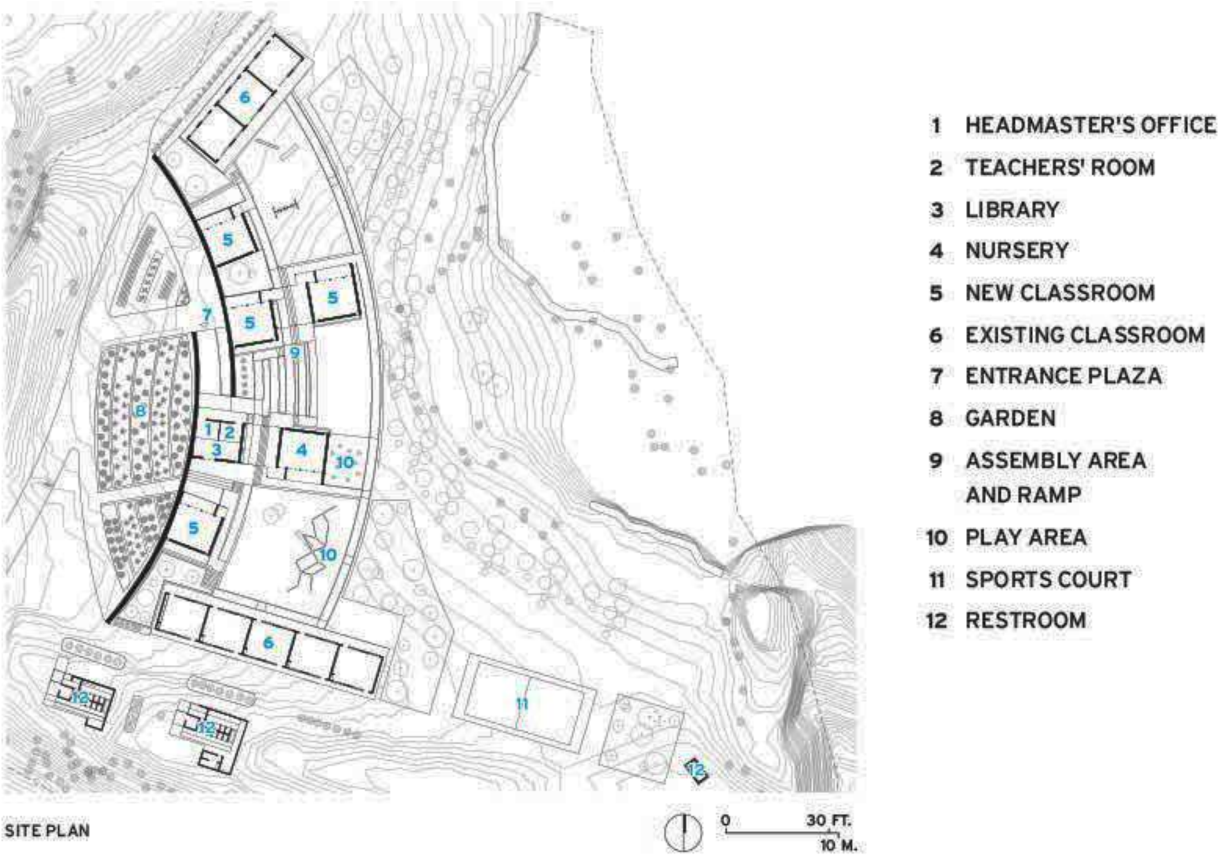


Figure 7.10. Site plan of Ruhehe Primary School (MASS Group, 2018)

Table 7.15. Climate Adaptation technologies implemented in the Early Childhood Development and Family Centres

	Overheating	Flooding	Storms	Drought
Building	-local materials -skylights -recycled materials -clay roof tiles -timber ceilings			-water tank
Infrastructure				
Resources				

The analysis shows no attempt to develop a project resilient to climate change, but there are a few technologies that can be helpful in dealing with overheating. These include clay roof tiles, timber ceilings, concrete floor tiles, tree bark and bamboo, window screening and recycled materials used for fencing, play equipment, toilet screens, and water tank screens.

7.2.8. Rwamagana Leaders' School Dormitory

Rwamagana Leaders' School is a secondary boarding school located in eastern Rwanda. ASA Studio designed a new dormitory building for this school with the aim of 'demonstrating the potential of empowerment in education through architecture' (Clegg & Sandeman, 2019). The building acts as a teaching tool that enhances the boarding school experience while stimulating the students and offering a safe and healthy environment. A participatory design approach was adopted, and students were engaged for their input. The spatial design is flexible to provide space for different activities required by students. The negative spaces created were used as common sitting areas. A summarised project description is presented in the table below.

Table 7.16. Rwamagana Leaders' School Dormitory project description

Architect	ASA Studio
Location	Rwamagana District, Rwanda
Client	Rwamagana Leaders' School
Area	835sqm
Project period	2015 – 2016

Similar to the previous precedents, this dormitory partially adapts to climate change, mainly heat adaptation. Passive ventilation was incorporated through implementation of perforations in the blockwork (figure 7.11). This improves thermal performance of the building through passive ventilation and night flushing. These perforations are rainproof. There are protruding bricks above them to shelter from rain. The building further has an open clerestory to ensure that there is unrestricted air flow (Figure 7.12). This also ensures that the heating effect of the metal roofs is mitigated.

Figure 7.11. Covered perforations on blockwork (Clegg & Sandeman, 2019)

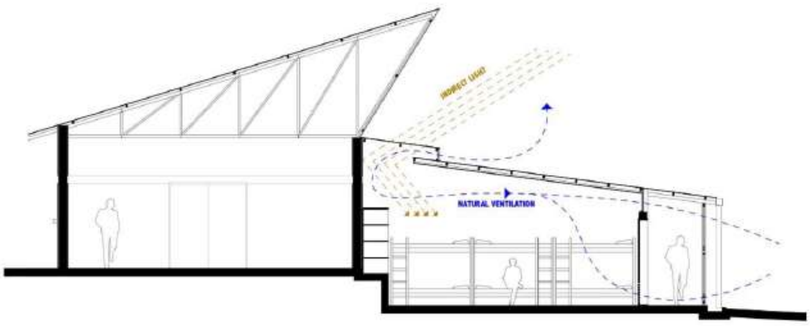


Figure 7.12. A section of Rwamagana Leaders' School (ASA Studio, 2015)

The use of sustainable and local material ensures comfort in the interior space as these materials have high thermal mass. They retain heat during the day and release it at night-time as a result of passive ventilation. The floors are made of earth, and they are cement free. Walls are built from locally fired bricks. Bamboo is used for screening in the windows, and river cane is used as a suspended ceiling in the bedrooms to resist solar radiation, control light and for aesthetics. Natural daylighting is also ensured using glass block windows next to each bed space. Diffused light also enters through the suspended river cane ceiling. Table 7.17 below presents results of the climate adaptation analysis of this precedent.

Table 7.17. Climate Adaptation technologies implemented in Rwamagana Leaders' School Dormitory

	Overheating	**Flooding**	**Storms**	**Drought**
Building	-wall perforations -clerestory -local materials with high thermal mass -earth and cement free floors -local fired bricks for walls -bamboo for screening windows -river cane for suspended ceilings			
Infrastructure				
Resources				

The result of the analysis shows this precedent to be resilient to extreme heat as a result of the alternative means of cooling the internal space: passive ventilation, use of thermal mass material and a few trees closer to the buildings. Natural daylighting ensures proper lighting even in the absence of power. There is, however, no mention of alternative power supplies nor water management adaptation technologies.

7.2.9. AWF Primary Schools

Two primary schools which form part of the 'Classroom Africa' program of the African Wildlife Foundation, similar to the Ilima primary school, are located adjacent to Kidepo Valley National Park in Karamoja/North-eastern Uganda. The schools were designed to cater for 350 students each. The aim of the development is to protect wildlife and encourage residents to live in harmony with wildlife rather than consider them as a threat to their livelihoods. Sustainable development was prioritised in this project which improved resilience to climate change. Table 7.18 presents a summarised description of the project.

Table 7.18. AWF Primary School project description

Architect	Localworks
Location	Geremech and Sarachom, Karamoja, Uganda
Client	African Wildlife Foundation
Area	2000sqm
Project period	2020

Building materials were sourced locally where possible, such as the stone which was used for foundations and plinth walls. The stones were collected by residents within a 3km radius of the site. They were set out in semi dry-stack formations creating a water mitigating substructure. Compressed earth bricks (CEBs), which was manufactured on site, is another local material that was used to form the upper part of the walls. This product provided an ecological alternative to the common 'village brick' as they call it, which promoted deforestation. The roof structure (Figure 7.13) was composed of very light and thin steel profiles which is said to have been fitted in a single truck for both schools. The aim was to ensure that the frames can be installed by manpower, without the use of machinery, and for affordability purposes.

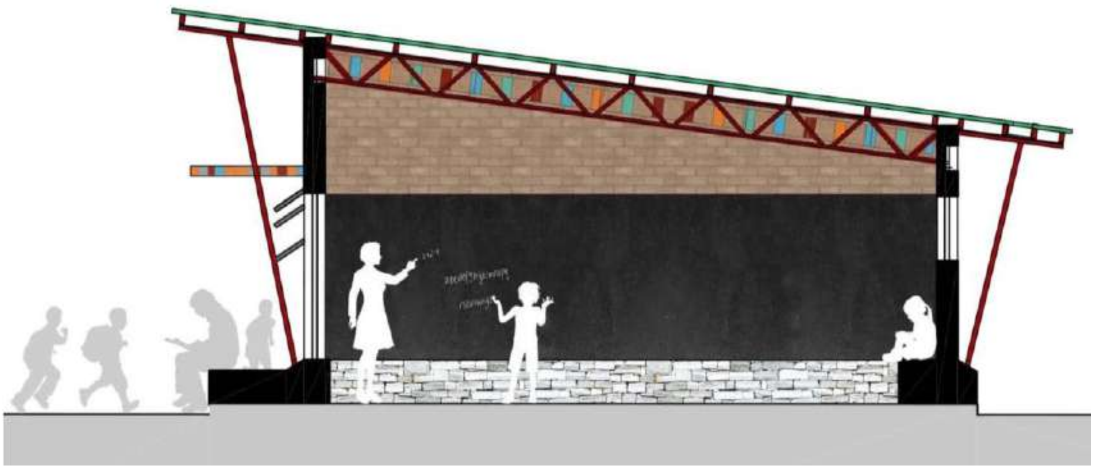


Figure 7.13. Cross section of AWF Primary's classroom (Localworks, 2019)

Windows and doors were formed of sliding and top-hung steel louvre panels which provide shading as well as security. These panels were multicoloured (Figure 7.14) as inspired by the local jewellery design and provided a maintenance-efficient response to shading. The landscape was designed to foster a relationship between nature and people, by protecting trees, adding local species, and introducing agriculture.

Figure 7.14. Multi coloured louvres (Clegg & Sandeman, 2019)

Green technologies such as rainwater harvesting, renewable energy generation (solar power), use of fuel-efficient wood stoves, and aqua privy toilets were implemented. Passive ventilation was designed to achieve indoor thermal comfort. Direct ingress of the sun was minimised through the use of thermal mass materials and proper orientation of the buildings to avoid overheating without using expensive mechanical systems.

It can therefore be concluded that this development used sustainable technologies, their combination of which led to resilience of some components such as heat management systems. The climate change adaptation technologies implemented in this project are presented in Table 7.19.

Table 7.19. Climate change adaptation technologies implemented at AWF Primary School

	Overheating	**Flooding**	**Storms**	**Drought**
Building	- steel louvres provided shading and encouraged ventilation. -passive ventilation was implemented to encourage indoor thermal comfort. - orientation and thermal mass combination	- locally found stones were used to form a water mitigation substructure (dry stack formations)		-Rainwater harvesting
Infrastructure				
Resources	-The planning encouraged a relationship between nature and people, conserved vegetation and added biodiversity.			

7.2.10. Mzuzu University Health Centre

The Mzuzu University health centre for AIDS and Malaria was designed by Feilden Foundation volunteer architects following a request by the university to design an affordable alternative to the university's expensive prefabricated buildings using imported materials. The aim of the architects therefore was "to provide the university with their own modular self-building system which would utilise locally sourced and sustainably produced materials and more significantly employ and develop the skills of local people" (Clegg & Sandeman, 2019:141). The project description is presented in Table 7.20 below.

Table 7.20. Mzuzu University Health Centre project description

Architect	ASA Studio
Location	15 districts in Rwanda
Client	UNICEF Rwanda
Area	500 sqm
Project period	2013 – 2016

The project has two phases. Phase One started in 2004 and it was designed as the Richard Felden Clinic, but now consists of the entrance and administration block. Then the next building is Phase Two of the project, and it is a treatment centre with examination and treatment rooms. This will be followed by a ward in Phase Three.

Figure 7.15. Front view of Mzuzu University Health Centre (Clegg & Sandeman, 2019)

This project was also designed to partially adapt to climate change, mainly extreme heat. The buildings are mainly oriented along the east-west axis, with openings predominantly in the north and south facades. The buildings are carefully spaced to ensure free flow of air for cooling purposes. The east-west elevations are shaded with existing trees that were not cut and trees that replaced those which were cut. The roofing (shiny galvanised 'alu-zinc' roofing sheets) reflects solar radiation, reducing heat transfer in the buildings. The roof has a modular cassette design with an inbuilt ceiling and ventilated air space which keeps the building cool. Foil insulation was also used to block radiant heat from penetrating to the space below. The table below presents the results of the climate change resilience of the precedent.

Table 7.21. Climate Adaptation technologies implemented in Mzuzu University Health Centre

	Overheating	Flooding	Storms	Drought
Building	-modular system -proper orientation - free flow of air -reflective roof sheets - foil insulation	-raised floors		
Infrastructure				
Resources	-replace cut trees			

7.2.11. Nakapiripirit Vocational Institute

Nakapiripirit Vocational Institute is a technical school located in Nakapiripirit, Karamoja, Uganda. Its focus is on agriculture and construction training. The school was previously (before 2017) dilapidated with some classrooms and dormitories unusable. The Ministry of Education and Enabel initiated a project to revitalise the school and curriculum to empower and strengthen the community as they build their own school. The school has a courtyard at its centre with buildings surrounding it. Those buildings include a new large workshop developed to provide hands-on training, and classrooms. Other buildings such as a new kitchen, brick laying and practice workshop, as well as water and waste management facilities, are scattered across the whole site. The table below presents a summarised description of the project.

Table 7.22. Nakapiripirit Vocational Institute project description

Architect	ProPlanPartners
Location	Nakapiripirit, Karamoja, Uganda
Client	MoES Uganda/Enabel
Area	504 sqm
Project period	2017 – 2019

The school incorporated a few climate change adaptation technologies mainly focusing on extreme heat, water management, and energy generation. The workshop walls have permanent openings to allow for cross ventilation and to flush out heat during the night time, as shown in Figure 7.16 below. This ventilation is also supplemented by mechanical ventilation such as eight wind cyclones on the roof ridge which extract moisture and warm air from the building whenever necessary. The new workshop was designed to maximise natural light with primary horizontal openings to evenly distribute the light inside the workshop and roof lights placed at the centre of the workshop. The walls are painted with reflective paint, and the ceiling insulation has a reflective surface which bounces the light in the interior space for proper lighting.

Figure 7.16. Nakapiripirit Vocational Institute buildings (Clegg & Sandeman, 2019)

The workshop is provided with photovoltaic panels to provide alternative energy. Solar panels are also provided in the existing ICT building. The kitchen has a solar water heater to preheat water thereby reducing the quantity of required firewood for cooking purposes. Water harvesting technologies were implemented. A 20 000-litre tank was built by students as part of their project. The tank is made from ISSB blocks and stores water harvested from roofs of existing buildings. Further, there are four PVC tanks for the new workshop, with two of them (10000 litres) on ground and the other two elevated. There is also a 16000 elevated tank near the kitchen supplied by water from a borehole. The table below presents results of the analysis of the precedent.

Table 7.23. Climate Adaptation technologies implemented at Nakapiripirit Vocational Institute

	Overheating	**Flooding**	**Storms**	**Drought**
Building	-wall openings -mechanical ventilation -roof lights -reflective painted walls -fire wood		-photovoltaic panels -solar water heating	
Infrastructure		-water harvesting (water tanks)		
Resources				

7.3. International Overview

The precedents in the previous section address mainly overheating impacts and focus on building designs. The impacts of change in rainfall patterns and wind were not explored and addressed, hence the need for analysis of a further selection of international precedents to learn from. Nine precedents were selected for analysis, with the purpose of learning about the application of climate change response technologies which also address flooding and storms. The purposely selected precedents from across the global south as well as Denmark, are listed in Table 7.24 below.

Table 7.24. Selected international precedents addressing climate related risks

	Case study	**Location**	**Risks addressed**
1	El Pozón, Cartagena de Indias	Colombia	Extreme heat, flooding, storms, and drought
2	Fiji indigenous housing	Fiji	Extreme heat, flooding, storms
3	Skt. Kjelds District and Tasinge square	Copenhagen, Denmark	Extreme heat, flooding, storms, and drought
4	Amphibious houses by Site Specific	Thailand	Extreme heat, flooding, storms, and drought
5	Lift house	Bangladesh	Extreme heat, flooding, storms, and drought
6	Community Library	Ambepussa, Sri Lanka	Extreme heat, flooding, and storms
7	Earth Village	Nam Dam Village, Vietnam	Extreme heat, flooding, storms, and drought
8	Jetwing Vil Uyana	Sigiriya, Sri Lanka	Extreme heat, flooding, and drought
9	Soneva Kiri	Koh Kood, Thailand	Extreme heat, flooding, storms and drought

7.3.1. El Pozón, Cartagena de Indias, Colombia.

El Pozón is a neighbourhood located on the outskirts of Cartagena, a major port and tourist centre on Colombia's Caribbean coast. Figure 7.17 below shows a topographical map of Cartagena. El Pozón neighbourhood developed in the early 1990s illegally, through an invasion of the southern bank of the La Virgen swamp by people from the rural areas (Veloza, Dadati, Giordano & Savio, 2022). This area consists of numerous buildings which arose spontaneously and were self-constructed without guidance from the building regulations. Some of these buildings are still illegal but others are now legal with residents having titles. The method of building, according to Veloza et al. (2022), is the main reason for the environmental problems, among others, which affected living conditions in this area.

Figure 7.17. Topographical map of El Pozón, Cartagena (TECHO Colombia, 2015)

These environmental challenges were caused by the rise in temperatures and sudden change in rainfall patterns (Veloza et al., 2022). This neighbourhood has been affected several times by flooding, with the most severe episode being in 2011 (Dadadi & D'Amico, 2020). It is affected by rainfall mainly because of its swampy context and heavy seasonal rainfall. The buildings are vulnerable to flooding since their construction was spontaneous and their relationship with nature was unplanned, according to Veloza et al. (2022). Further, the domestic water supply is a challenge in the dry season since the residents rely on rainwater for drinking. The lack of water further affects agriculture, making cultivation very costly. The soil is also not suitable for cultivation since it used to be swampy but was later filled with construction waste. The infilling of the swamp continues, and it is claimed to be causing damage to the area's natural system (Dadadi & D'Amico, 2020).

The challenges discussed above attracted different responses from academia. The Pontificia Universidad Javeriana (PUJ) in Bogota and Politecnico di Torino initiated a project called PEI Máquina Verde - El Arca to foster the resilient and sustainable development of the neighbourhood. A housing prototype of the project was developed and further built for the international competition Solar Decathlon Latin America and Caribbean (SDLA&C) in 2019, which took place in Cali, Colombia. The team which proposed this house further proposed a concept to integrate Nature-Based Solutions (planting vegetation in recycled containers placed on roofs) into the house's plumbing system to collect clean rainwater. These were proposed on private and public spaces. On private spaces they were implemented in roofs and backyards.

Blue - green roof and rain gardens are also options that were proposed for currently built houses in the neighbourhood to improve access to water for domestic use. A summarised description of this area is presented in Table 7.25 below.

Table 7.25. El Pozón project description

Architect	Pontificia Universidad Javeriana, and Politecnico di Torino
Location	Cartagena, Colombia
Client	Government of Colombia
Area	Not disclosed
Project period	2019

The prototype house has a C-shaped layout with a central patio. This form encouraged circulation, passive ventilation, and exposure to natural light, blending the inside and outside spaces. The house was designed to be flexible as it is reconfigurable with features which can be added or removed based on the occupants' requirements. Ventilation was achieved through passive technologies taking advantage of prevailing winds. These technologies further provided protection from solar radiation. The building has 10 photovoltaic panels positioned on its fixed roof of the social areas to address energy needs. Five prototype panels that were developed, assist with the provision of hot water. A hydro sanitary system was designed with two sources: potable water supplied from the aqueduct, and rainwater from the roof surface. The purpose of this system was to encourage reduced water consumption through water reuse and efficient water storage. Gutters are installed for water recollection, and the gutters further connect to downpipes. A range of local materials were identified for use in the building. Some of the waste materials were used to build modules.

There are two modules that were designed: a fixed module and a moveable module. The fixed one had a lower tank in which water overflow was collected. The way the module works, it replicates a green roof. When it rains the water filters to the ground. The rain garden, on the other hand, connects to the traditional rainwater collection system through some pipes. Veloza et al (2022) discuss in detail how the blue-green roofs (Figure 7.18) and rainwater gardens function.

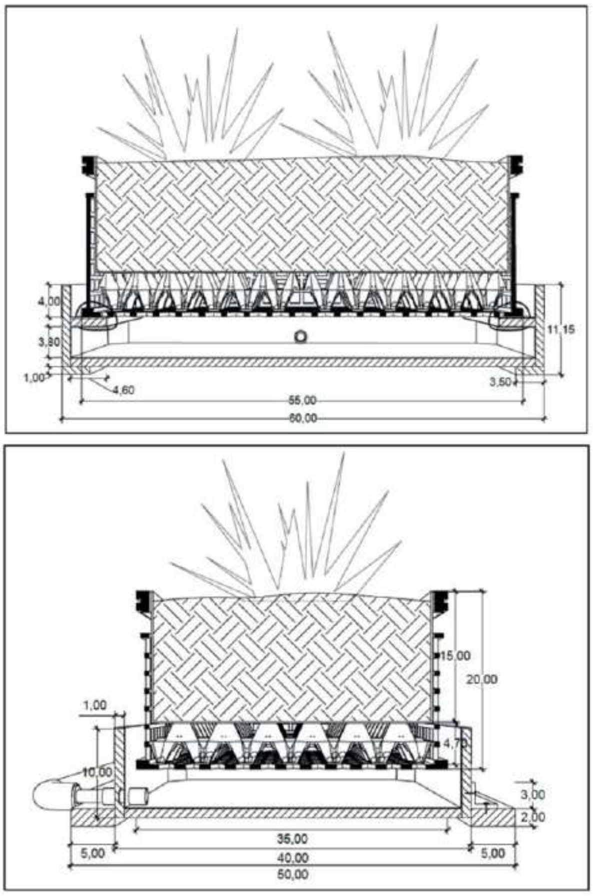


Figure 7.18. Sections of the blue-green roof module (Dadati & D'Amico, 2020:145)

Benefits anticipated at a larger scale include reducing environmental pollution through improved waste management. Water is also stored and used for sanitation activities and growing fruits and vegetables. The blue-green roof module is a low tech modular and a scalable solution which can contribute to mitigation of extreme storm water events because of its drainage capacity. Further, this technology decreases the impact of waste materials disposed of and enhances the value of water resources. Even though this project seemed to be focusing on an individual building, there was a part of the research which focused on understanding the relationship between the building and the surroundings. A network of the blue-green roof modules and rain gardens can contribute to the health and wellbeing conditions of the entire community. The technologies discussed are summarised in Table 7.26.

Table 7.26. Climate Adaptation technologies implemented in El Pozon

	Overheating	**Flooding**	**Storms**	**Drought**
Building	-central patio encouraging ventilation and natural light -configuration of the	-blue green roofs -rainwater gardens	-photovoltaic panels and solar collectors -use of local materials	-blue green roofs - for water consumption, a hydro sanitary system was

	windows to take advantage of prevailing winds and protection from solar radiation			designed with two sources: potable water supplied from the aqueduct, and rainwater from the roof surface. -gutters and tanks for water storage
Infrastructure		-green public spaces		
Resources	-replace cut trees -water is stored for growing fruits and vegetables			

7.3.2. Fiji indigenous housing

The Republic of Fiji is a small island state in the Pacific Ocean, very prone to natural disasters such as cyclones, strong winds, floods, earthquakes, and tsunamis. Fiji is almost the size of Eswatini with an area of 18 333 square kilometres and a population less than that of Eswatini, which is 865 611 people mainly (87%) residing on the two largest islands, Viti Levu and Vanua Levu.

The country was recently (2016) hit by Tropical Cyclone Winston (TC Winston) affecting approximately 540 000 people (62% of the population) with 30 000 houses being destroyed. Cyclones in this country are claimed to affect housing structures and provision of temporary housing and reconstruction support especially in rural areas. Construction of housing in these islands has been using new material which proved difficult to import and required specialised skills, which delayed reconstruction. Fijian traditional houses have proved to be an alternative solution to housing recovery (Fujieda & Kobayashi, 2013) and seem to have some resilient capabilities worth replicating in similar contexts. The selected precedent below reviews resilient capabilities of vernacular architecture specifically that of Fiji.

Figure 7.19. Navala village (MARIMIYAJI et al., 2017)

Navala village, with 140 households in 2017, is one area that was affected by the cyclone; however, it was observed that over half of the traditional houses, called bures in Fiji, remained standing after the storm. In a study conducted in Navala village, the respondents who were the residents of this village considered the bures (well maintained and properly constructed) as safer than modern houses during cyclones and similar natural disasters. The author concluded by stating that these Fijian traditional houses are resilient to disasters. Serlet (2020) also stated that these thatched houses adapt well to the climatic condition of Fiji. The composition of these houses is described in the following paragraphs.

Figure 7.20. Fijian traditional house (MARIMIYAJI et al., 2017)

The foundation of the structure is composed of a platform with large boulders and earth raised from 300 mm up to 900 mm or more above the ground. The main structure is composed of wooden corner posts and wall posts. These are secured in the ground before the stone platform is built. The roof system is composed of wooden roof frames. These are tied together using coconut fibre ropes. Thatch from grass or palm leaves is then laid as a roof cover. The walls on the other hand are formed of mats made of woven bamboo or reeds attached on the external side of the posts often supported by small posts to reinforce the walls in the centre. Grass thatch is also used sometimes to create walls. The houses are sometimes bound together using ropes composed of natural materials.

Resilient construction practices include the planning of the settlement pattern to include scattered buildings which helps in cutting wind flow. The vegetation around the settlement also helps in reducing wind speed. Wind is also addressed by having a 45-degree hipped four-sided configuration of the roof, extended eaves, and strong corner posts buried sufficiently to reduce uplift of the roof by strong winds. The round shape gables assist in resisting wind.

Concerning adaptation to flooding, the house sits on mounds which also protects the house from storm surges. Stones are placed around the mounds to protect the soil from eroding. The steep roof allows rainwater to shed quickly away from the building to increase durability of the thatched roof.

In terms of adaptation to overheating, the house has improved ventilation as the floor is elevated and the thatch roof is high. The wall thickness varies depending on the season, as in dry season only the reed is lashed together forming a screen which allows ventilation, and during the wet season the screen is lined with thatch on the outside. There are generally moveable interior screen walls in the case when privacy and security, among others, is required. An open space is normally well ventilated. Windows are not provided to allow for a cool indoor environment.

If a collapse does occur, the lightness of the structure makes it less life threatening, and since the structure is woven together, it is less likely to fly off. Modernising the structure by replacing thatch with corrugated iron, however, makes these structures unsafe. A summary of adaptation technologies is presented in Table 7.27 below. There are no technologies captured for adaptation of infrastructure and resources to overheating, flooding, storms and drought. However, the use of indigenous methods is known to conserve the natural environment which promotes biodiversity.

Table 7.27. Climate Adaptation technologies observed at Naval Village

	Overheating	**Flooding**	**Storms**	**Drought**
Building	-high thatched roof and elevated floors to improve natural ventilation. -adjustable walls - thickness of walls varies depending on season. -moveable interior walls. -windows are not provided to allow for a cool indoor environment.	- mounds and stones around the mounds protect the house from storm surges. -steep roof sheds water quickly	-scattered planning of buildings to cut wind flow. -vegetation breaks wind speed. -steep roof and strong corner posts to reduce uplift of the roof by winds.	
Infrastructure				
Resources				

7.3.3. Sankt Kjelds and Tasinge Squares

Denmark is one of few countries that have made great strides towards adaptation to climate change, mainly adaptation to heavy rainfall, from which other countries can learn. Copenhagen is claimed to be the first city that has pledged to become fully carbon neutral by 2025. There are strides which the city has already taken towards realisation of the vision following the predicted future effects of climate change. The city is, therefore, being prepared for the future climate.

Copenhagen has undergone transformation since 2013, under the Climate Change Adaptation Plan (2011), to adapt to the effects of climate change such as strong and heavy rainfall. The neighbourhood, Sankt Kjelds in the North-Eastern part of the city which sits on an incline sloping down to the harbour, was partially revitalised in 2014 as a response to the approximate $1 billion of damage due to flooding in July 2011. To address this, Sankt Kjelds' local architecture firm, Tredje Natur, developed a master plan to address water management and other flooding issues. The aim was to achieve greener streets, front gardens, abundant wildlife, and green solutions to redirect or retain the rainwater in the event of future flooding. A brief description of the project is presented in Table 7.28 below.

Table 7.28. Copenhagen program description

Architect	Tredje Natur
Location	Sankt Kjelds District. Outer Osterbro in Copenhagen
Client	Copenhagen municipality
Area	105 hectares
Project period	2011 – 2016

The initiative of developing climate adaptation solutions was planned and partially implemented together with the residents. The citizens contributed local knowledge, ideas, and resources in different projects. The climate adaptation program encompassed different projects including Tasinge Plads, Bryggervangen and Sankt Kjelds Plads. The projects are all mainly addressing flooding issues but the proposed and partially implemented ideas also have potential of addressing overheating and wind pressure.

Figure: 7.21. Sankt Kjelds' Square, Tasinge Square, and Bryggervangen (Tredje Natur, 2011)

Tasinge square (Figure 7.22) was created after a discussion with the residents of the area who presented ideas for the project, which was previously used for activities such as Christmas markets, concerts, and theatrical events.

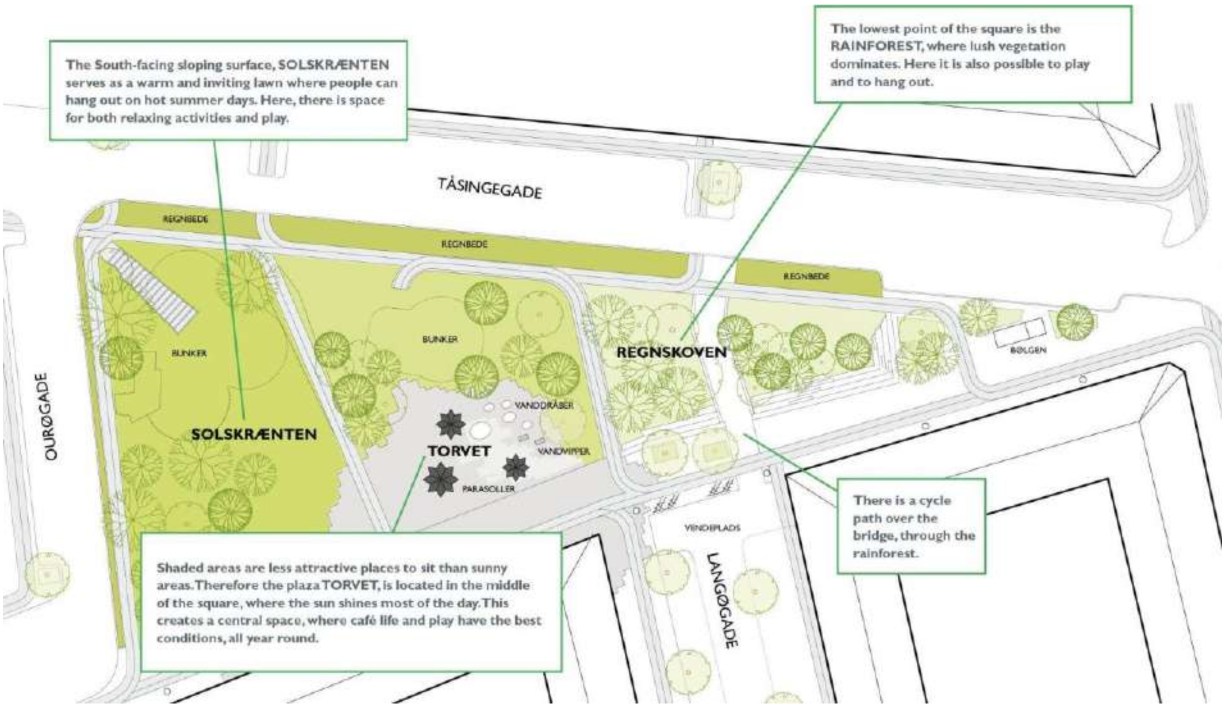


Figure 7.22. Site map of Tasinge Square (Tredje Natur, 2011)

Asphalt estimated at 1 000 square metres was transformed into a large green area forming part of the park. This reduced pressure on drainage systems with the introduction of greenery which absorbs rainwater. This clearly ensured adaptation of the environment not only to flooding but also extreme heat, wind effects, and other climatic impacts. The vegetation for the square was selected in consideration of food for birds and insects and a great seasonal diversity accommodating a great biodiversity. Plants tolerating fluctuating humidity were also provided for the square's lowest area.

At the centre of the square sit two sculptures resembling raindrops and the other, rain parasols (Figure 7.23). The 'parasols' collect rainwater and provide shelter from rain. The 'raindrops' reflect the sky and their surroundings because of their metallic reflective surface, which attracts people to touch and climb them. This encourages social gatherings within the park. The lowest point of the square which has lush vegetation is also a possible place to play and hang out. Rainwater from roofs of surrounding houses is collected through drainpipes and diverted to reservoirs underneath the big "water drops" sculptures. From there, water is pumped by stepping on a tilt plate (playing) and will flow to the rain forest where it will slowly infiltrate. Most of the rainwater falling on the square is separated from the sewer system.

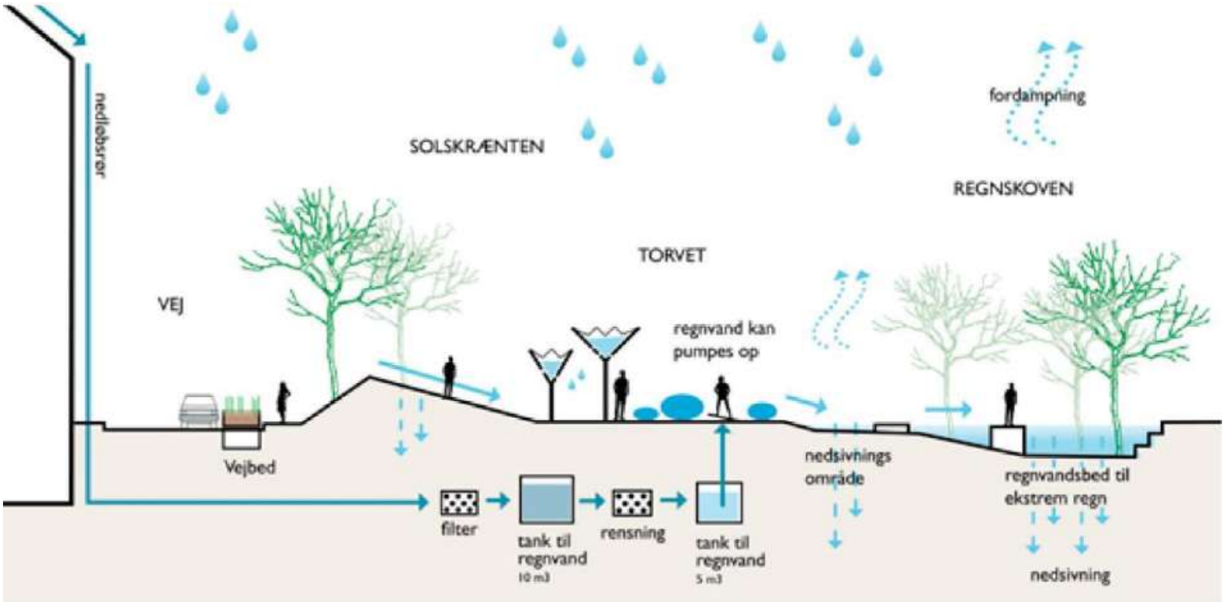


Figure 7.23. Water management in the Tasinge Square (Tredje Natur, 2011)

Road water, on the other hand, flows into swales containing infiltration trenches which are on the roadside. The water infiltrates through a thin outer layer of earth which filters contaminants such as oil.

It is apparent that Tasinge square can receive and handle large quantities of rainwater as the rain bed on the square can be filled up to 40% in rain events that occur once every 100 years.

In cloudbursts which occur once every 500 years, the rain garden will be totally filled up such that the water will run from Tasinge square to the cloud bursts street (street with vegetated storm water drains) of Tasingegade where it will eventually be directed into the harbour not very far from the square.

It is apparent that the project was mainly meant for adaptation to flooding, which occurs often in Copenhagen, however the implemented nature-based solutions further double as adaptation solutions to overheating. These methods can be replicable in public areas of low-cost housing settlements through assistance of municipalities with residents participating as the case in Copenhagen. This precedent proves that retrofitting is seen as effective in view of how hard surfaces were converted to permeable surfaces to ensure adaptation of the settlement to flooding. The projects implemented were meant to address adaptation at neighbourhood level and did not get to the level of addressing adaptation of the buildings in the neighbourhood to climate change. The identified climate change solutions from this precedent are presented in Table 7.29. below, with some of the interventions (resources) cutting across all four risks. Developing biodiversity for instance, helps in the adaptation of flora and fauna to extreme heat, flooding, storms, and drought.

Table 7.29. Climate Adaptation technologies implemented at Copenhagen

	Overheating	**Flooding**	**Storms**	**Drought**
Building	- gutters collect rainwater from roofs which is directed to underground reservoirs			-water harvesting
Infrastructure	-more open spaces and reduction of hard spaces reducing urban heat islands -retention basin (rain garden) which has a cooling effect -part of asphalt transformed to green area -flowers, shrubs planted along streets -rainwater is separated from sewer system -water from roads is infiltrated through swales and directed to underground tanks			
Resources	-development of green urban space which supports social life (urban furniture, cycle paths, play water, etc) -diversity of vegetation for different climates and different soils -biodiversity -lush vegetation			

The solutions identified specifically address issues of water management by reducing pressure on drainage channels and introducing public spaces within the city of Copenhagen which absorbs rainwater, stores rainwater, and redirects water to the harbour in the case of extreme flooding. This has increased the adaptive capacity of infrastructure to flooding, while also adapting the social dimension through encouraging play and a relationship between nature and humans. Furthermore, the infrastructure dimension adapts to urban heat islands through the reduction of hard ground surfaces and introduction of vegetation. The diversity in the vegetation and overall biodiversity ensures adaptation of the environmental dimension to flooding and extreme heat, having vegetation that withstands different weather patterns. Buildings harvest water and directs excess water to underground reservoirs. These are systems that are recommended for adapting to drought.

7.3.4. Amphibious house by Site Specific

Thailand is one of several countries in Asia that have been affected by flooding in the past couple of years. It is claimed that the floods would sometimes occur in areas where there was no history of floods before, and the floods are normally more intense than previous events.

A permanent solution was sought for affected communities to live with the floods through adaptation of their buildings since relocation was seen not to solve the challenges which come with the floods. The government of Thailand engaged two architectural firms, Site Specific and Prefab Laboratory, to come up with a lasting solution to the property damages and life-threatening issues caused by flooding. In the past, most people built their homes near the rivers, and the buildings were equipped to deal with flooding as they were built on stilts and some homes were built as rafts. As homes are now built mostly on solid ground, these technologies are no longer used, and the houses built are no longer appropriate for flooding. The two companies, therefore, came up with floating houses that can rise and fall with the water as explained in the following paragraphs. The Amphibious house (Figure 7.24) was designed by Site Specific in Thailand to adapt mainly to flooding but further offer backup systems.

Figure 7.24. Amphibious house (Site Specific, 2011)

Table 7.30 below presents a summarised description of the project.

Table 7.30. Amphibious house project description

Architect	Site Specific
Location	Thailand
Client	Government of Thailand
Area	Not specified
Project period	Not applicable

The house was designed using a prefabricated steel floating system which sits in the trench below the house to hide it and to allow the depression to collect water when it rains. As the water level rises, the depression is filled with water and the house will start floating in the case of flooding (Figure 7.25). The building is kept in place by a slip-column system that allows the building to move vertically with the water.

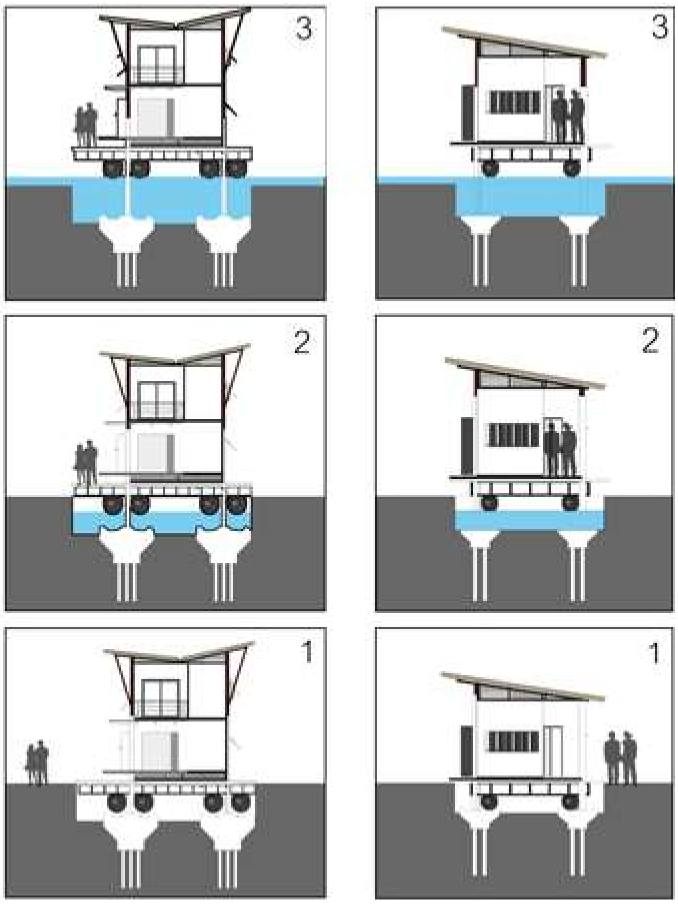


Figure 7.25. Floating system (Site Specific, 2011)

The house is designed to use prefabricated panels with steel framing to make the buildings lighter than conventional houses. The amphibious houses further have built-in backup systems which include food storage, rainwater collection, and power generation systems which enable the houses to function even if the city utilities fail.

Figure 7.26. Exploded view of the amphibious house (Site Specific, 2011)

The houses are arranged in groups of 5 to 10 (Figure 7.27) to form a mini community in times of flooding so that families can assist each other when there is a need before the arrival of external help. This helps the community to be self-sustainable for longer periods.

Figure 7.27. Grouped houses by Site Specific (Site Specific, 2011)

There are four different types of buildings which make up the community: residential buildings, commercial buildings, residential and commercial hybrid buildings, and civic buildings. This accommodates most of the needs of the residents. The residential buildings occupied by the residents of the community. Commercial buildings are used as small shops, farm stands, and food stalls. Residential and commercial hybrid buildings are adaptable and flexible buildings allowing residents to personalise their homes. Civic buildings are used as multipurpose, and they have the capacity to adapt and transform to suit a particular event of the day. The diversity of function (mixed use development) increases the resilience of the neighbourhood since the different buildings would respond differently to perturbations. Further, in the case of inaccessibility to the neighbourhood due to blocked roads because of storms for instance, the residents can still survive as most services are available within the neighbourhood. This proposed concept does not only focus on resilience at building level but also at neighbourhood level. The Table 7.31 below presents identified resilience and design ideas from the amphibious house concept.

The amphibious response may not be relevant to the context of Eswatini; however the mixed-use development and incorporation of built-in systems is a unique contribution of this precedent hence its inclusion for analysis. This contribution can be applicable in informal settlements in the context of Eswatini and similar contexts. The idea of using light prefabricated panels for buildings is also a useful idea to speed up the reconstruction of the buildings after a disturbance. Lighter buildings are also much safer since they reduce the mortality rate in the case the buildings fall apart after a climatic event.

Table 7.31. Climate Adaptation technologies implemented in the Amphibious houses

	Overheating	**Flooding**	**Storms**	**Drought**
Building	-flexible/convertible buildings -mechanical ventilation	-prefabricated steel floating system (moves horizontally -prefabricated panels make building lighter	-mixed use development	-rainwater collection
Infrastructure			-power generation system and electricity	
Resources	Food storage			

7.3.5 The Lift House, Bangladesh

Bangladesh is located within the deltaic floodplains of two of the world's largest rivers, making it vulnerable to flooding and responsible for draining large volumes of water flowing from neighbouring countries and from the Himalayas mountains. Flooding is mostly as a result of overflowing of rivers and internal water logging such as in the following years: 1954, 1955, 1970, 1980, 1987, 1988, 1998 and 2004, affecting city dwellers. Flooding can inundate 85% of the city of Dhaka to depths ranging from 0.3 to 4.5 meters, such as the case of the 1988 flood. Flooding is expected to worsen as a result of current and predicted future melting of the Himalayan glaciers, resulting in overflows of the river systems in Bangladesh.

Flooding in this country has the most impacts on the urban poor mostly living in informal settlements. The country is failing to adapt these areas to flooding, however there are a few concepts that have been proposed which seemed to be effective, such as the lift house pilot project which has gained recognition as one of many solutions to climate adaptation. The United Nations has also funded ecosystem-based approaches to adaptation especially in the Drought-prone Barind Tract and Haor "Wetland" Area. We learn from the lift house project (Figure 7.28) to understand several options that can be implemented to ensure adaptation of areas to climate change (flooding in this case). The following sections provide a brief overview of the lift house project in Dhaka.

Figure 7.28. The Lift House

The lift house (low-income flood-proof technology) pilot project was designed and constructed by a master's degree graduate, Prithula Prosun in Dhaka, Bangladesh, as a sustainable house for the low-income group in areas affected by flooding. The lift house was built for two families, and it was inaugurated in 2010 by the agriculture minister of Bangladesh. A summarised project description is presented in Table 7.32 below.

Table 7.32. The Lift House project description

Architect	Prithula Prosun
Location	Dhaka, Bangladesh
Client	Low-income families living in flood prone communities
Area	Not discosed
Project period	2010

The two units are similar, and each unit has two levels with the ground level consisting of rainwater cistern, reusable water cistern, dwelling space, composting latrine storage and a vegetable garden. The first-floor level consists of dwelling spaces with kitchens and a shared composting latrine above the latrine storages (Figure 7.29).

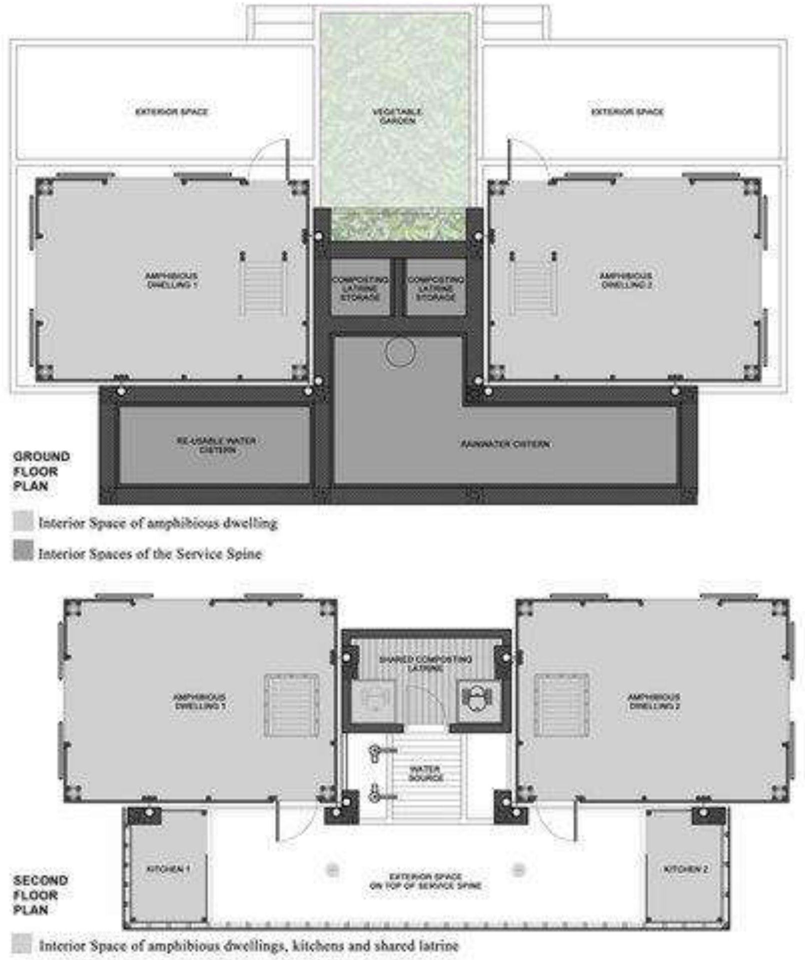


Figure 7.29. Floor layouts of the Lift house

The lift house floats upwards with rising water levels as a result of flooding and water logging. When the water recedes, the house returns to ground level. There are two types of foundation systems used in the house to achieve buoyancy which allows the house to float on water. Empty plastic water bottles are packed into the foundation of the first dwelling to provide buoyancy, and on the second dwelling a hollow Ferro cement foundation is used for buoyancy.

In addition, the house is self-sustaining, and it is independent of the city's service systems. Water is harvested and filtered, electricity is provided from two 60W solar panels for lighting and fans, along with composting toilets, and all other required services are provided to its residents.

The main wall material used is bamboo because of its availability locally and for being a fast-growing local renewable source. It is promoted as a green material and claimed to be low cost when compared to corrugated tin. So, bamboo is seen as a material that provides a safe and comfortable environment which is affordable to the low-income groups. It is easy to produce locally with very little technology.

The Lift house is one example of a climate adaptable house, and the following table presents identified resilient practices that were used in this building to adapt it mainly to flooding.

Table 7.33. Identified climate change solutions from the Lift House project

	Overheating	**Flooding**	**Storms**	**Drought**
Building	-the use of bamboo further adapts the house to overheating to a certain extent, as bamboo is known to have a cooling effect	-the house floats with rising water level preventing excess water from affecting contents of the house	-the house is further self-sustaining in terms of electricity, as it has 60W solar panels used for lighting and running fans. -the use of local material (bamboo) allows for a quicker response should the house be affected by climate disturbances	-harvests rainwater that can be used in extended absence of rain
Infrastructure				
Resources				

The technology of floating in the lift house may not be relevant for Eswatini since informal settlements sit on steep topography. However, the use of local materials, self-sustaining nature of the house (lighting and fans), and water harvesting, are relevant strategies we can learn from. The use of local materials which are easy to assemble and disassemble increases the resilience of a building since the response rate could be high in the case such houses are affected by climatic events.

7.3.6. Community library, Ambepussa, Sri Lanka

A new library situated inside the Sri Lankan Regimental Headquarters, was built by the Sri Lankan army following the civil war (1983-2009) which destroyed the social fabric of Sri Lanka. The architects, Milinda Pathiraja and Ganga Ratnayake, designed a building that could be easily assembled anywhere by anyone. The library now serves the base and neighbouring villages and connects the army and community in the process. A summary of the project description is presented in Table 7.34 below.

Table 7.34. Community library project description

Architect	Robust Architecture Workshop
Location	Ambepussa, Sri Lanka
Client	Sinha Regiment, Sri Lanka Army
Area	Gross floor area: 1,402 sqm, Site Area: 16,605 sqm
Project period	Completed 2015

The building was designed in harmony with nature and has building components which adapt to climate change impacts. The form of the library is a linear arrangement of orthogonal building blocks which are made with modular steel portals and rammed earth walls (Figure 7.30). The building adapts to extreme heat with the employment of passive design technologies. The building has ventilation shafts, and its narrow form allows for cross ventilation with the windows placed on opposite walls. The walls are made of thick (300mm) rammed earth which is considered a very sustainable solution due to its low embodied energy, small materials treatment process, long service life, and high recyclability. Earth walls contribute to good indoor thermal comfort when combined with proper passive ventilation. Rammed earth walls slow heat transfer into and out of the building and keep the internal room temperature comfortable.

Figure 7.30. Community library design, Sri Lanka (Robust Architecture Workshop, 2020)

Further, the natural systems were preserved and improved which made them adapt to climate change impacts. In the construction of the library, there was no cut and fill of contours, but some part of the building touched on the ground and other rested on pilotis. This design also ensures uninterrupted storm water runoff and movement of animals. The buildings were placed in between trees to minimise cutting them. The trees lost during construction were replaced by twenty new trees (Kishnani, Dutta & Ramkumar, 2019). The conservation of the natural systems retained and further improved existing ecosystem services.

Material for construction, such as soil for the earth walls, timber for flooring and cladding, and steel, was sourced locally, within a 2-kilometre radius. This makes it easier and quicker to rebuild the structure to its previous condition (engineering resilience) if it is affected by natural disasters. Climate adaptation technologies implemented in the Community library project are summarised in Table 7.35 below.

Table 7.35. Climate Adaptation technologies implemented in the Community library project

	Overheating	**Flooding**	**Storms**
Building	- ventilation shafts -narrow building form for cross ventilation -use of high thermal mass material (rammed earth)	-building stand on pilotis allowing storm water to flow under the building	-use of steel portals for strength -use of locally available materials which can reduce reconstruction time
Infrastructure			
Resources	-replace cut trees -building above ground: building rest on pilotis -no cut and fill of contours		

7.3.7. Earth Village, Nam Dam Village, Quan Ba District Ha Giang Province, Vietnam

The nongovernmental organisation Caritas Switzerland (Vietnam) explored an idea of an integrated community project in Quan Ba District with the purpose of raising environmental awareness and offering vocational education. This idea was explored through piloting the Nam Dam village, a village that lacked sanitation, which was causing frequent outbreaks of disease among farm animals. This village also had low agricultural yields and uncertain weather, which affected farming and local income. Nam Dam village was relocated from the mountain slopes to the nearby foothills, closer to services. The architects, which were led by Hoang Thuc Hao, developed the idea over a period of 10 years until a new settlement, Earth Village, with 51 households, was realised. A summary of the project is presented in Table 7.36.

Table 7.36. Earth Village project description

Architect	1+1>2 Architects
Location	Ha Giang Province, Vietnam
Client	Caritas Switzerland (Vietnam)
Area	Community house: 600sqm, Typical homestay: 60-80 sqm
Project period	Completed January 2015

The typology of the homestay is influenced by a traditional house, and the community's social structure and available resources informed the village's form. The layout consists of clusters (Figure 7.31) of about five to seven houses sharing a rainwater collection system and biogas digester.

Figure 7.31. Aerial view of the Earth village, Vietnam (Vu, 2015)

This precedent had traces of resilience to climate change effects. The project used locally sourced materials such as stone, bamboo, clay, and timber which were harvested in a nearby forest. Clay for rammed earth walls was acquired on site. The availability of material locally makes reconstruction of the buildings quicker in the case they are affected by extreme weather events.

The buildings adapt to flooding as they channel surface runoff into a pond which is later used for irrigation during the dry season. The availability of water supply systems improves food security. Further, each home harvests water through rainwater tanks which hold about 500 cubic sqm of water annually. The buildings adapt to extreme heat through the use of passive ventilation such as opposite windows and skylights with vents. A microgrid was installed to distribute power within the Earth Village. Each cluster of buildings shares a digester which converts accumulated biomass into gas for cooking and heating. Solar panels are placed on rooftops of the community houses and the school to generate energy. Table 7.37 presents a summary of technologies which adapt to climate change.

Table 7.37. Climate Adaptation technologies implemented in Earth Village project

	Overheating	Flooding	Storms
Building	- cross ventilation -air vents on rooftop - high thermal mass materials i.e., rammed earth	-water harvesting: underground water tank, water tank	-locally sourced material -solar panels, biodigester, microgrid
Infrastructure		- rainwater collection pond	
Resources	-water harvesting systems to sustain food security		

7.3.8. Jetwing Vil Uyana, Sigiriya, Sri Lanka

Jetwing Vil Uyana (JVU) was built during a civil war in Sigiriya, Sri Lanka, with a vision of connecting the development with history and nature. The land on which the development sits was abandoned farmland, contaminated with agricultural chemicals. Following regeneration of this land, it is now considered one of the top five eco luxury lodges in the world. It consists of 36 villas and resort amenities. A summary description of this project is presented in Table 7.38 below.

Table 7.38. Jetwing Vil Uyana project description

Architect	Sunela Jayewardene Environmental Design Pvt Ltd
Location	Rangirigama, Sigiriya, Sri Lanka
Client	The Royal Heritage Hotel Pvt Ltd
Area	Gross floor area: 11,668 sqm, Built-up area: 74,868 sqm, Site: 10.7ha
Project period	Completed 2006

The development incorporates green technologies, which makes the development ecologically friendly, and has potential of adapting to climate change effects. The intention of this development may not have been so much about creating a climate change resilient development, but the sustainable principles used contribute to increasing the adaptive capacity of the development to climate change impacts which we can learn from. The development includes 1.6 hectares of water bodies. Rainwater is collected by these water bodies and filtered by 3 hectares of wetlands. Excess water is redirected to enter the local catchment (Figure 7.32). The villas are elevated above ground so that they do not disrupt the movement of animals and water. This system adapts to extreme rainfall, with the rainwater also used for irrigating several hectares of land, improving food security.

Figure 7.32. Jetwing Vil Uyana, Sri Lanka (Jetwing Hotels, 2021)

Biodiversity was introduced into the site by including vegetation that attracts birds and butterflies, as well as citrosa for its mosquito-repelling properties. Diversity is also observed in trees and fish species. Following this development, species counts jumped with 29 species of birds which were recorded on site in 2006 increasing to 101 species by 2019. Fauna now includes otters, monitor lizards, monkeys, peacocks, crocodiles, and occasional elephants.

The buildings were built entirely of natural materials which were locally sourced. The roofs are thatched using coconut palm and painted using natural dyes. This improves passive comfort. Waste is sorted and sold for recycling, and horticultural waste is used in the garden or sold as organic fertiliser. Food waste is collected and used as animal feed. Addressing waste keeps the environment clean and allows it to address climate change impacts such as naturally absorbing rainwater. Agricultural practices such as vegetable gardens which deliver annual yields of 600 kg of rice and 1 000 kg of fresh produce improve food security.

The design of the buildings reduces energy demand and saves over 2.4 million kWh/year (Kishnani, Dutta & Ramkumar, 2019). Table 7.39 below presents a summary of climate adaptation technologies used in Jetwing Vil Uyana.

Table 7.39. Climate Adaptation technologies implemented in Jetwing Vil Uyana

	Overheating	Flooding	Storms
Building	- cross ventilation -villas can be opened to air and light	-buildings are elevated above ground to allow water to flow underneath -water harvesting: underground water tank, water reservoirs, water catchment	-locally sourced natural material
Infrastructure			
Resources	-water harvesting systems (underground garden tank, water reservoirs) to sustain food security -waste is sorted and sold for recycling -horticulture waste is used as organic fertiliser -agricultural practices i.e., rice production, fish production -biodiversity: vegetation that attract birds and butterflies, diversity of tree and fish species		

7.3.9. Soneva Kiri, Koh Kood, Thailand

Soneva Kiri is a resort located on Koh Kood Island in Thailand. This development, which was completed in 2010, consists of 36 villas, seven restaurants, gym, spa, and staff residences and amenities. The total gross floor area of the 36 villas is 28 324 square metres. A summary description of the project is presented in Table 7.36 below.

Table 7.40. Soneva Kiri project description

Architect	Habita Architects
Location	Koh Kood District, Thailand
Client	Soneva
Area	28,324 sqm
Project period	Completed 2010

The villas used vernacular design and local craft (Figure 7.33). The whole concept incorporated ecologically friendly design principles which contribute to climate change adaptation of buildings. The following paragraphs discuss the technologies identified and how they improve the climate adaptation of the development.

Figure 7.33. Soneva Kiri Building (Habita Architects, 2010)

Trees that were found on the site were not cut, but they became part of the design. Trees that could not be left in place were transplanted to accommodate a building. The villas were built on land which had few mature trees. Sometimes villas were moved where there was a tree. Fourteen indigenous tree species were planted with the goal of creating biodiversity and attracting seed-disbursing birds which leads to a viable ecosystem.

Drinking water is sourced and bottled on site, and all produce is local. The food produced is used in the resort's kitchen and neighbouring villages. About 10% of the resort's food needs are met through the vegetable and herb gardens. All solid waste is separated and recycled. Used cooking oil is converted to biodiesel which is used to power some of the resort's pickup trucks. Shredded garden waste is mixed with kitchen waste, and this goes to an earthworm farm which converts it into compost used for vegetable gardens. There is a pig farm which uses organic waste from kitchens.

The development further invests in renewable energy such as wind turbines, photovoltaic solar panels and a micro hydro turbine.

Bamboo, mostly used in Asia, was used to form the structure of some of the buildings. Low embodied energy materials, recycled waste products, and green building techniques were employed throughout the development. Foundations used sandstone boulders extracted locally. Some of the timber was harvested, dried, and treated on site. A pottery kiln was used on-site to produce terracotta pipes and spouts for rainwater collection. Soil extracted on site was mixed with rice husks and straw to produce adobe mud bricks and plaster for the interior walls.

A green roof was built on the villas using soil that was excavated to make way for a pond. Rainwater is circulated through reed beds filled with aquatic plants which cleans it. Almost 100% of the water consumed is harvested rainwater. All wastewater is recycled and used for irrigation purposes.

The Villas are kept cool by using a green roof, high thermal mass materials, and operable openings; and each villa has a skylight which allows daylight into the building. Table 7.41 summarises the climate adaptation technologies implemented in Soneva Kiri.

Table 7.41. Climate Adaptation technologies implemented in Soneva Kiri

	Overheating	Flooding	Storms
Building	- cross ventilation -villas can be opened to air and light - high thermal mass materials	-buildings are elevated above ground to allow water to flow underneath -water harvesting: underground water tank, water reservoirs, water catchment	-locally sourced natural material
Infrastructure			
Resources	-water harvesting systems (underground garden tank, water reservoirs) to sustain food security -waste is sorted and sold for recycling -horticulture waste is used as organic fertiliser -agricultural practices i.e., rice production, fish production -biodiversity: vegetation that attract birds and butterflies, diversity of tree and fish species		

7.4. Discussion

The precedents selected for analysis locally and internationally use green building technologies to adapt to climate change. The approach of using green building technologies to develop the adaptive capacity of the precedents to climate change does not necessarily consider the attributes of resilience such as diversity, modularity, and redundancy. If considered, it does not seem intentional. However, it is undeniable that the use of green building technologies can be leveraged to increase the adaptive capacity of building projects. The study identified a number of green building technologies and design strategies from the precedents that have the potential to contribute to the resilience of settlements.

The following sections discuss these strategies drawn from the precedents according to their potential for allowing settlements and buildings to adapt to extreme temperature effects, extreme rainfall effects, and extreme wind effects. The discussion compares the findings from precedents with views from interviews of experts drawn from academia, municipalities, independent climate change consultants, government, and parastatals. These are the same interviews conducted to respond to the first research question as reported in Chapter 5. These experts were also questioned about their views on how climate change impacts can be addressed. The experts were asked through a semi-structured interview to respond to the question, 'how can effects of climate change be addressed?' The assumption is that the experts will give effective proposals since they are directly or indirectly involved in analysing, researching and addressing climate related effects, and they relate to the context of the study. The results are presented in the subsections below.

7.4.1. Addressing temperature effects

The precedents selected from the Manifesto (Clegg & Sandeman, 2019) mainly addressed extreme temperature effects, due to their location in Eastern Africa where high temperatures are common. These precedents provided a comprehensive set of strategies for addressing extreme heat, which were also confirmed by the international precedents. Themes which relate to temperature adaptation of buildings include site planning, building components, passive ventilation, flexibility, and building performance.

The study found that site planning is critical in addressing extreme heat effects. Proper orientation of buildings sensitive to prevailing wind direction is also critical in cooling buildings. Fresh air enters any windward opening, and it is exhausted from any leeward opening (Walker, 2016), therefore this should be considered in the orientation of buildings to address extreme heat. Further, spacing of buildings affects ventilation, with buildings arranged in high densities, such as the case in most informal settlements, potentially hampering airflow and therefore the potential for natural ventilation. Buildings should be carefully spaced to create sufficient space for circulation of air in-between them. Furthermore, buildings should ideally have a shallow depth or one room depth with windows on opposite walls to encourage cross ventilation. A one room depth eliminates internal partition walls that affect cross ventilation. The addition of internal walls in buildings has compromised natural ventilation in buildings (Walker, 2016).

Adapting buildings to extreme heat can also be ensured through using elements of the building, such as painting roofs with a colour that will reflect radiation rather than absorbing it. Large overhangs were used in precedents to shade walls and windows, and in some cases high thatched roofs were employed. Studies have shown that as the ceiling height increases in a building, thermal comfort increases (Hashimoto & Yoneda, 2009). Ceilings can also be suspended, as was the case in some precedents, to create an air gap which prevents that transfer of heat from roof coverings which absorb heat. Walls in most precedents in the East African countries used local materials with high thermal mass to slow the transfer of heat into the building during extreme heat conditions. During cold nights, the heat gained is retained to maintain good thermal comfort.

Passive ventilation technologies are also employed in precedents through different ways such as wall perforations normally created above the windows and doors, roof vents, steel louvres, and solar chimneys to allow hot air to escape and create buoyancy. There are cases where roof sheets are perforated, however, it is not clear how such methods prevent access of rainwater into the buildings. Solar chimneys are hollow components which connect the inside part of the building to the outside part. Air inside the chimney is heated and rises when the sides of the chimney walls are heated by solar radiation. A vent at the top of the chimney is kept open so this heated air is not trapped. This heated air is pulled up and out of the chimney, pulling new air in from the outside and creating a sort of "draft" that provides cool, fresh air into the building. This is an affordable method of cooling the internal space when compared to mechanical ventilation.

Further, natural ventilation, which contributes to adaptation of the building to extreme heat, is ensured through developing a flexible building. Flexibility in this context refers to the use of building components that can be adjustable whenever a need arises. Some of the precedents used moveable interior walls which can be shifted to adjust natural ventilation. In some cases, the whole buildings are moveable and can be relocated to suitable, less vulnerable areas. The use of operable windows allows occupants to regulate the ventilation depending on the need at that time.

With regards to infrastructure, adaptation to extreme heat is ensured through the use of open spaces, wetlands, and water retention for cooling purposes. In Copenhagen for example, asphalt was replaced with open/green spaces which was useful in regulating temperature to reduce urban heat island. Trees and vegetation contribute to cooling by lowering surface and air temperature through providing shade and through evapotranspiration. Water retention and wetlands on the other hand cools nearby areas through evaporation.

Extreme heat, flooding, and storms also affect resources such as agriculture and green networks which provide ecosystem services to the residents. These natural systems adapt to these effects through practices that encourage biodiversity. Precedents also present conservation of vegetation through replacement of cut trees as a common strategy. Further, building on wetlands was avoided to preserve them. All the effects of climate change were addressed through similar strategies.

The results from the precedents addressing settlements to extreme heat are compared with responses from interviewed experts in Table 7.42 below. The results from precedents and results from interviews match and align with similar themes. However, precedents presented more detailed information concerning adaptation to extreme heat. The interviewed participants were not design experts but based their suggestions on their observation of the context since they work with climate related issues. In all the results there was an emphasis on the use of locally available building materials with the understanding that they are affordable and therefore easier to replace should a building be altered to address temperature effects or recover from an extreme weather event.

Table 7.42. Identified strategies for addressing extreme temperature effects

	Themes	Precedents	Interviews
BUILDING	Building Planning	-shallow building depth -proper orientation -careful spacing of buildings in an order -group houses for proximity	-orientation that captures wind
	Building components	- Roofing: reflecting roofing, large overhangs (shading walls and windows), double skin roof -Ceilings: damp proof ceiling, suspended plastered ceilings, river cane for ceilings - Walls: local materials, local fired bricks for walls -Floors: earthen floors, elevated floors - Windows: open clerestory and skylights, bamboo for screening windows, no windows, use louvres	-Walls: Non heat conductive materials -Roofing: thatched roof -General: Affordable climate smart buildings, locally available materials, alternative affordable materials, retrofitting existing buildings
	Passive Ventilation	-cross and stack ventilation -wall perforations/cut outs -perforated roofing sheets -internal walls at ⅔ of ceiling height -roof vents -perforated doors and windows -solar chimneys -double door (internal panel with burglar and mosquito net) -mechanical ventilation	-Use louvres
	Flexibility	-modular system -reconfigurable elements -configurable windows -adjustable wall thicknesses -moveable interior walls -flexible buildings/convertible	
	Building performance		-reduced energy consumption
INFRASTRUCTURE	Open spaces	-more open spaces -asphalt to green area	-porous pavements -pavement which increase heat radiation
	Water retention	-retention basin (rain garden)	-cooling reservoirs -man-made wetlands
RESOURCES		-green patios (different species) - conserve vegetation, replace cut trees -biodiversity - avoid building on wetlands	-planting trees
	Design awareness		-proper design awareness -regulatory body forums Campaign

Further, participants and precedents highlighted passive ventilation for cooling purposes within a building. This may require retrofitting of the building envelope for existing buildings in order to respond to the current and future high temperatures. Interviewee 2 stated, '...when we construct the buildings, we should look at the winds of the area, how windows should be positioned to capture wind for ventilations purposes…'. The precedents also presented many approaches which orient buildings according to prevailing winds to cool buildings.

The precedents presented several building components which need to be adjusted to adapt buildings to climate change. Participant 1 was not specific on which components of the building envelope should be altered but still highlighted that the design of the envelope should be climate responsive. Participant 6 raised the same idea and clarified by stating,

> "So, Issues of designing houses which are able to be cool when it's hot outside, also probably being able to build the houses with materials which will not absorb heat. For instance, roofing sheets, it's not everyone who can afford a ceiling, but using corrugated iron is the only option we have. Can't we go back to using thatched roof? Because corrugated iron absorbs a lot of heat."

Some of the precedents used suspended ceilings to avoid the transfer of radiation to the building. Participant 7 stated that they have built houses roofed with metal sheets for affected residents in a certain area in Lavumisa, but the residents do not use these houses because it becomes very hot inside them in summer since Lavumisa has high temperatures. This supports the idea that alternative materials which do not absorb heat should be considered to ensure internal comfort even on hot days.

Participants of interviews did not mention any strategies which relate to flexibility of the building possibly since they are aware that it may not be affordable in the context of Eswatini. With regards to infrastructure, evaporative cooling and use of green infrastructure seem to be emphasised. Participants discussed planting trees for cooling purposes. Participant 4, for example, was concerned that, '…developers never consider planting trees for example, which is one natural response to the increasing temperature.' Participant 8 raised a similar point, stating that the urban heat island effect should be addressed through planting trees. He suggested consideration of cooling reservoirs where possible.

7.4.2. Addressing flooding effects

Flooding effects were mainly addressed in the international precedents. The analysis brought up several themes of addressing flooding effects such as: water collection methods, building envelope, amphibious systems, flexibility of elements, and alternative energy systems. The water collection methods reduce the volume of storm water by harvesting rainwater through downpipes and water tanks. Some projects go to the extent of using underground water tanks, which however might prove expensive for informal settlements. Blue-green roofs and rainwater gardens are also used by some precedents to absorb water and reduce rainwater runoffs. Rain gardens refer to depressions with a garden of shrubs, perennials, flowers, or other vegetation, formed on a natural slope to increase rain runoff reabsorption by the soil. Since these systems use natural means, they are affordable and applicable in different residential contexts.

The building envelope of buildings observed to adapt to flooding effects is designed to shed water quickly from the surface of the buildings through the use of steep roofs and waterproof wall materials to avoid water absorption of materials. Some of the waterproof materials using affordable methods include plaster made of clay-sand mix, white clay, and boiled palm oil.

Buildings also adapt through amphibious systems such as prefabricated floating systems. Such systems allow the building to move vertically and rise in the case of water rising from flooding and move down after the floods. Some houses sit on stilts to allow water to flow under the buildings without affecting the occupants of the buildings. In some cases, precedents use mounds of stones to raise the floors of buildings above the flood level.

Infrastructure on the other hand adapts to flooding effects through technologies that were categorised under the themes: water retention, water supply, waste management system, and energy. Water retention technologies such as long swales which in some cases lead to underground tanks, underground reservoirs, and rainwater collection systems, reduce the velocity of storm water flow and further reduce rain runoffs that floods the neighbourhoods. These technologies reduce pressure on engineered storm water drainage channels and can alleviate the pressure on infrastructure such as roads and bridge, avoiding excessive damage.

Precipitation events also affect water supply systems whose adaptive capacity should be improved to keep them functioning even when affected by such events. These effects mainly relate to drought which is expected to worsen as rainfall declines with time. Technologies identified which address water supply include rainwater harvesting, boreholes, water reservoirs, and the use of underground water pumps. A combination of all these methods, with others acting as backup systems, can be more effective in addressing drought effects.

Table 7.43 presents themes identified after thematic analysis of the strategies implemented in precedents, and they are compared with suggestions from interviewees.

Table 7.43. Identified strategies for addressing precipitation effects

	Themes	Precedents	Interviews
BUILDING	Water collection	-water harvesting/tanks -blue-green roofs and rainwater gardens -ground water supplies	-water harvesting -groundwater supplies
	Building envelope	-materials: plaster made of clay-sand mix, white clay and boiled palm oil, recycled materials, porous concrete -steep roof with gutter system	-materials: local and recycled materials, porous concrete -retrofitting building envelope -design for future climate -resilient structures delivered through government housing schemes
	Amphibious systems	-water mitigation sub-structure using stones -prefabricated floating system -stands on stilts -floating house -moulds of stones	
	Flexibility	-reconfigurable elements	
	Energy systems	-photovoltaic panels	
	Building performance		-water reuse -water use control -water control technology
INFRASTRUCTURE	Water retention	-long swales, swales lead to underground tanks -underground reservoirs, rainwater collection - porous concrete pavement	
	Water supply	-rainwater harvesting, boreholes, water reservoirs, underground water pump -reduce water leakages	
	Waste management system	-biodigester -ecological sanitation technology -separable rainwater from sewer system	
	Energy	-power generation system and electricity	
	Drainage		-green areas -upgrading drainage networks
RESOURCES	Green networks	See table 7.32	

The interview participants were further given an opportunity to contribute their ideas on how they believe the challenges of flooding, as well as other precipitation effects, can be addressed. Like addressing temperature effects, participants raised strategies that were classified under different themes which align with some themes from precedents. The building category had themes such as water collection, building envelope, and building performance. These strategies were similar to those identified in precedents in exception of amphibious systems.

Such systems were not raised in interviews possibly because of the context of Eswatini which is mountainous. Concerns of flooding in such contexts relate mostly to high velocity flow of rain runoffs rather than rise of water levels, therefore amphibious buildings may not be that effective in the Eswatini context in addressing flood effects.

The issue of using local materials was also raised by interviewees to address precipitation effects. The advantage of using locally available materials is the fact that, in the case the building is destroyed by flooding, it is easier, quicker and more affordable to rebuild or refurbish it back to its original or improved state since material can be readily available close to the affected site. The materials should not only be locally found but also recyclable, according to Participant 3. Participant 6, also on materials, stated that there is a need to identify materials which contribute to adaptation in each climatic zone. He mentioned that the thinking that one solution works for every place should be avoided. He further suggested design participation as he believes the communities can come up with better solutions since they experience the problems. Participant 7 brought up the same point when given a chance to comment, 'Yes, we are doing what we term climate smart structures, but more insight would be helpful in trying to adapt to those climate smart structures in the different regions because we can't be doing a blanket approach.' One solution according to the participants cannot be claimed to work for all regions with different climates.

Climate data shows that rainfall is declining, which resulted in a drought season in Eswatini in 2015 to 2016 where all dams dried up. Water retention and water supply methods suggest introduction of water harvesting technologies in all buildings which also address drought effects. The same sense was received from participants as Participant 3 stated, '...That can be addressed by changing housing design to adopt water harvesting systems, wastewater reuse, and preparing ground water supplies for future consumption… Otherwise we need to reuse wastewater in gardens and to irrigate our lawn.'

One suggestion which came from participants who understood the context suggested replacing the current water management infrastructure to keep the systems functioning. Participant 5, aligning with Participant 4's suggestions, stated that the drainage channels and storm pipe networks can no longer fulfil their function adequately during heavy downpours. He stated that these networks need to be upgraded and designed according to current and projected future climate data. He further suggested the upgrading of green networks. 'Green areas are required to reduce the runoffs and relieve pressure to the drainage systems' stated Participant 5 who has a background in road maintenance.

The awareness and use of local climate data by developers is one critical contribution made by most participants. Participant 4 relayed a concern stating, 'what we don't normally do when designing our neighbourhoods is studying rainfall patterns.' Further, the same participant criticised the town planning scheme stating that it does not address or speak into issues of climate change. He further admitted that they have realised the need to include the issues of climate change, and further informed that they are looking into developing policies that will eventually feed into the legislation in an attempt to address climate related issues in general.

7.4.3. Addressing wind effects

The precedents highlighted little when it comes to adaptation of settlements to storms, mainly wind effects, yet it is expected that as global warming increases, uneven heating of the earth will result in stronger winds. Themes derived through thematic analysis of the precedents include growing windbreaks, building a wind barrier/diversion, and improving the structural integrity of buildings. Windbreak methods identified included planting trees on the building yard and using scattered layouts to cut wind flow. With wind diversion, buildings use steep roofs, which also prevents roof uplift by winds. Another strategy employed is improving the structural integrity of buildings to withstand high pressure winds. Table 7.44 below presents the combined wind strategies implemented in precedents, and they are compared with suggestions from interview participants.

Table 7.44. Identified strategies for addressing storm effects

	Themes	Precedents	Interviews
BUILDING	Windbreak	-trees on yard -scattered planning to cut wind flow	
	Wind barrier/ diversion	-steep roof	-parapet walls -use fascia boards
	Structural integrity	-strong corner posts -local materials	-retrofit roofs
INFRASTRUCTURE	Wind management	Limit tree height (to avoid trees falling on power lines)	-green recovery -limit tree height -establish windbreaks
RESOURCES		See table 7.32	

With reference to the context, Participant 1 stated that they frequently (annually) addressed effects of wind in some low-cost housing in Matsapha (Eswatini) because the roofs were exposed to wind and set on the wind corridor. The participant stated that this occurred until they built parapet walls to shield the roof from this strong wind. Participant 7 raised a point about the use of facia boards which, he stated, can protect roofing from being blown away by strong winds. The participant further suggested short overhangs also to prevent the roofs from being blown away. However, this strategy conflicts with the strategy of broad overhangs to provide shade in extreme weather. Short overhangs therefore should be implemented only in zones where strong winds are the major concern, or else find solutions of developing a proper structural integrity in the case broad overhangs should be implemented. These suggestions from participants aligned with the theme of wind barriers as identified in precedents.

Participant 8 also suggested retrofitting of roofs to withstand strong winds. Since winds normally affect roofs the most, most participants have ideas around addressing the roof systems. 'And of course, it's the roof that gets blown off by strong winds, so you need to design that properly' stated Participant 8 who is also a climate change researcher and consultant. The use of locally available materials was also suggested to address wind effects because of the same reasons stated in the previous sections.

Vegetation was promoted by most participants as necessary for reducing wind pressure. Participant 5 stated though that vegetation sometimes causes problems as big trees can fall and block roads during strong winds. However, he admitted that we need trees to provide a wind break and absorb water from runoffs, but stated that they should be carefully selected, and their heights should be maintained frequently.

Participant 6 suggested that wind direction should be studied for proper orientation of the buildings. This aligns with all suggestions proposing the use of climate data in the design of houses not only to address wind impacts but all other impacts that relate to climate change. Government housing schemes are suggested by Participant 7, who made reference to a similar solution in Brazil: "A solution here would be that type of scheme like they have in Brazil where you find that the community… there is that building of houses for each other using proper material". This solution could help mainly in controlling quality and ensuring proper use of relevant technologies addressing climate change, which residents would not afford or be aware of. Participant 11 discussed the change in regulations and building standards with which developers should align, stating that: "There should be regulations for constructing even in rural areas. There should be standards. The buildings should at least meet certain standards, at least meeting requirements to address local challenges".

Different design strategies aimed at addressing climate change effects were identified through analysis of precedents around the globe, mostly from projects implemented in the global south countries. However, some may not work in the context of Eswatini even when they are effective in other countries in different regions. The interviewed local participants who understand the context of Eswatini provided a sense of strategies that could work in Eswatini based on their general observation and experience of the effects of climate change in Eswatini. The synthesised strategies from precedents and interviews are presented in Table 7.45 below.

Table 7.45. Consolidation of climate change adaptation technologies from precedents and interviews

		OVERHEATING	FLOODING	STORMS
1	BUILDING	**1.1. Heat management systems** **1.1.1. Planning** -shallow building depth -proper orientation -careful spacing of buildings in an order -group houses for proximity **1.1.2. Building components/ envelope** - Roofing: reflecting roofing, large overhangs (shading walls and windows), double skin roof, high thatched roof -Ceilings: damp proof ceiling, suspended plastered ceilings, river cane for ceilings - Walls: local materials, local fired bricks for walls, non-heat conductive materials -Floors: earthen floors, elevated floors - Windows: open clerestory and skylights, bamboo for screening windows, no windows, use louvres -General: Affordable climate smart buildings, locally available materials, alternative affordable materials, retrofitting existing buildings **1.1.3. Ventilation** -cross and stack ventilation -wall perforations/cut outs -perforated roofing sheets -perforated roofing sheets -internal walls at ⅔ of ceiling height -roof vents -perforated doors and windows - opposite windows -solar chimneys -double door (internal panel with burglar and mosquito net) -steel louvres	**1.2. Water management system** **1.2.1. Water collection** -water harvesting/tanks -blue-green roofs and rainwater gardens -ground water supplies **1.2.2. Building envelope** -Materials: plaster made of clay-sand mix, white clay and boiled palm oil, recycled materials, porous concrete -steep roof with gutter system **1.2.3. Amphibious** -water mitigation sub-structure using stones -prefabricated floating system -stands on stilts -floating house -mound or foundations of stones **1.2.4. Flexibility** -reconfigurable elements **1.3. Energy systems** -photovoltaic panels -hydrosanitory system -waste management [reuse and recycling]	**1.4. Wind management systems** **1.4.1. Windbreak** -trees -louvres -scuttered planning to cut wind flow **1.4.2. Wind block and diversion** -steep roof -parapet walls -facia boards **1.4.3. Structural integrity** -strong corner posts -local materials

		OVERHEATING	FLOODING	STORMS
		-mechanical ventilation **1.1.4. Flexibility** -modular system -reconfigurable elements -configurable windows -adjustable wall thicknesses -moveable interior walls -flexible buildings/convertible **1.1.5. Building performance** -reduce energy consumption		
2	INFRASTRUCTURE	**2.1. Heat management systems** **2.1.1. Open spaces** -more open spaces -asphalt to green area -pavement which increase heat radiation **2.1.2. Water retention** -retention basin (rain garden) -cooling reservoirs -man-made wetlands	**2.2. Water management system** **2.2.1. Water absorption and retention** -long swales, swales lead to underground tanks -underground reservoirs, rainwater collection - porous concrete pavement **2.2.1. Water supply** -rainwater harvesting, boreholes, water reservoirs, underground water pump -reduce water leakages **2.2.2. Waste management system** -biodigester -ecological sanitation technology -separable rainwater from sewer system **2.2.3. Energy** -power generation system and electricity	**2.3. Wind management** Limit tree height (to avoid trees falling on power lines)
3	RESOURCES	**3.1. Green networks** -green patios (different species) - conserve vegetation, replace cut trees -biodiversity - avoid building on wetlands		

7.6. Conclusion

The aim of this chapter was to address the second sub-research question with the objective to investigate how other projects have addressed adaptation of residential settlement components to climate change with an intention to meet certain urban sustainability goals. This study was critical in identifying design strategies which can be implemented to build resilience of settlements to climate change for consideration in the context of informal settlements in Eswatini. Thematic analysis of each precedent was conducted starting with theoretically derived categories: building, infrastructure, and resources. Under each category, sub themes were developed based on the coded data of identified existing design strategies. The design strategies were grouped based on the climate change effects they address such as overheating effects, flooding effects, and storms.

Buildings address overheating through planning, building envelope elements, ventilation, flexibility of form, and building performance. The planning of the buildings has to do with spatial arrangement of the buildings to allow free flow of air, proper orientation to avoid direct sunlight, and ensuring the building form is planned to be narrow to allow for cross ventilation. The building components such as roofing, walls, floors, ceilings, and windows are also designed to regulate heat gain in the building by allowing free flow of air for cooling, retaining heat during the day, and reflecting radiation. The analysed precedents also used ventilation as means to ensure building comfort even during hot days. Passive ventilation is the most common method used by creative wall perforations, use of louvres, ensuring wall heights do not go up to ceiling height, use of solar chimneys, and keeping doors open during night hours, among other methods. Some strategies highlight flexibility of form as one way to address overheating in buildings. A flexible building is one that has configurable elements which can be adjusted to allow for a different function or building performance. Moveable internal walls for instance can ensure better passive ventilation during hot days and improve internal comfort.

The results also identified design strategies of buildings to adapt to flooding which includes water collection, adjusting the building envelope, developing amphibious houses, flexibility of buildings, and adapting energy systems. Water collections include water harvesting which collects rainwater normally from roofs to minimise runoffs on the yard of buildings. Building envelope is designed to resist water absorption of the building material and to allow free flow of air to avoid mould which is a health hazard. In some countries, amphibious houses have been developed such that the buildings float when water levels rise. This, however, could be an expensive technology to implement in informal settlement upgrading, especially where the houses are self-developed and managed by the residents. Flexibility of buildings is also identified as critical in addressing flooding by allowing some elements to be reconfigurable to avoid damages to the interior of the buildings. This goes to the extent of having a house that can be disassembled in the case of unbearable and disastrous weather conditions and relocated to a safer location. Alternative energy systems are proposed for buildings to act as backup systems in the case the main energy supply systems are affected by floods.

There are a few identified design strategies employed in buildings to adapt to storms which come with very strong winds. A few strategies include the use of trees as windbreak, use of parapet walls and facia boards to block winds from blowing off the roofs, and improving the structural integrity of the buildings such that they are not affected even during heavy storms.

Infrastructure on the other hand is also designed to adapt to the impacts of extreme heat, flooding, and storms. However, these strategies require donors and involvement of government or non-profit organisations as they can be costly for informal settlement residents to implement. Adaptation to extreme heat requires development of open spaces to minimise urban heat islands and provide shading to residents. Water retention also cools the neighbouring households and reduces the temperatures around that area through evapotranspiration. Flooding, on the other hand, is addressed through water absorption through the use of nature-based solutions, and retention to minimise unguided water runoffs that can affect households and natural environment. Nature based water management technologies can also reduce the pressure from hard infrastructure like storm water channels. There are also identified strategies which adapt the water and energy supply systems through provision of alternative systems to keep the settlements functioning. There are no practices aimed at adapting settlements to strong winds except for the provision of trees to act as windbreaks.

With regards to resources, the reviewed climate adaptation precedents and expert interviews did not present many strategies. The identified strategies highlight promotion of biodiversity and avoiding building on wetlands. Biodiversity provides sufficient resilience to climate change effects since there is a possibility of having plants that will adapt to extreme heat when others do not survive.

The strategies identified from precedents were compared with results from interviews with experts in Eswatini in an attempt to bring a discussion on what precedent strategies can work in the context of Eswatini. Since the experts understand the context, their contribution is also valued and synthesised with strategies that have been observed to work in other countries, especially countries in a similar context.

The strategies identified provide a sense of the type of components of settlements which should be addressed to adapt to climate change, and the technologies that should be implemented. Literature suggests however that resilience is ensured upon development of the attributes such as diversity, redundancy, and modularity into the components. For instance, having one water management technology such as water harvesting does not mean the system is resilient, but it is the diversity of water harvesting and supply systems, including porous pavements, swales, and boreholes, that ensures that the system is resilient. This part of the study provided green technologies which can be used to create diversity, redundancy, and modularity into settlement components to increase their adaptive capacity. Some of the precedents may not necessarily have a high adaptive capacity to climate change; however, the technologies used are relevant and may contribute to the development of design strategies of informal settlements to adapt to climate change to respond to the main research question of this study. The following chapter proposes how these green technologies can be combined to develop the adaptive capacity of informal settlements to the specific climate change adaptation risks in Eswatini.

PART III: OUTCOME OF THE STUDY

Chapter 8: Design strategies for Informal Settlements in Eswatini towards Climate Change Resilience

8.1. Introduction

There is an urgent need to build climate resilience in informal settlements to protect them from climate hazards and reduce risks to the residents living in these inadequate living conditions (UN Habitat, 2018). This chapter synthesises findings from the first three sub-objectives to propose strategies that can increase the adaptive capacity of informal settlements to the impacts of climate change. Sub-objective one, which aimed to determine the climate change risks for informal settlements in Eswatini, contributes to the development of the strategies by determining the climate change risks to which design strategies of informal settlements need to respond. This provided an overall frame for the strategies.

Sub-objective two: 'to assess the adaptive capacity of informal settlements in Eswatini', contributes to the development of the strategies by identifying areas and components of informal settlements that are vulnerable and degraded or enhance resilience to propose relevant solutions. This part of the study revealed how vulnerable and resilient informal settlements are in the context of Eswatini, and identified areas that require intervention to improve their adaptive capacity to the risks which were identified in the meeting of the first sub-objective.

The third sub-objective: 'to investigate existing approaches to climate change adaptation of settlements', aimed to learn from existing approaches to similar challenges. This part of the study explored a number of global precedents to identify responses to the vulnerabilities similar to those identified in the study area, Msunduza, Eswatini. These design approaches established a base from which to create the design toolkit which was the final outcome of the study.

The goal of sustainable urban development and urban resilience is to sustain the capacity of informal settlements to provide benefits to society. Such benefits (what is of value to residential settlements) were indirectly determined from the results of the interviews as: provision of affordable accommodation, human comfort, environmental health, safety, food security, good structural integrity, free movement, sustainable services, equality, and economic benefits. The study proceeded from the assumption that these benefits can be sustained through improving the resilience of settlements to the impacts of climate change that affect the provision and advancement of these benefits. The goal which the resilience strategies aim to achieve therefore, is sustaining the valued attributes/benefits of informal settlements.

Upon identification of the design strategies, it was critical to evaluate their suitability in the context of informal settlements in Eswatini especially since the strategies were based on international responses to climate change. Part of this chapter, therefore, aims to respond to the fourth sub-objective of the dissertation: “to evaluate design strategies that can be suitable for informal settlements in Eswatini to increase their adaptive capacity to the impacts of climate change.” This was achieved through conducting a survey and focus group discussions with experts drawn from academia and built environment related fields, who evaluated the proposed design strategies. The results of the evaluation of the proposed design strategies informed a proposed design toolkit which could be used to increase the adaptive capacity of informal settlements to the impacts of climate change.

The following section presents the synthesis of the findings presented in Chapter 5, Chapter 6, and Chapter 7, and proposes possible design strategies for informal settlements. Further, the findings from the survey and focus group discussions are presented to identify the strategies suitable for the context of Eswatini. Finally, the chapter is concluded by presenting the design toolkit as the output of the study to respond to the main objective of the study: “to determine design strategies that can be implemented to increase the adaptive capacity of informal settlements to climate change in Eswatini.”

8.2. Synthesising findings

The first part of the dissertation sought to understand the main issues of concern and further determine the valued attributes of the informal settlements; identify climate change impacts and risks to which informal settlements should adapt; and determine the components of the settlement which should adapt to the climate change impacts and risks. The main issue of concern, which also aligns with the problem of the study, emanates from general observations and disaster management reports which present the observed problem of vulnerability of informal settlements to climate change. This vulnerability leads to risk of degradation of these areas causing them to lose their function with time. A settlement that has lost some or all the valued attributes is deemed poorly functioning.

Interviews conducted with a diverse mix of experts in different fields affected by climate change unpacked three categories of climate change risks (on the physical dimension of a settlement) which can also be referred to as the issues of concern to which the settlements should adapt:

environmental effects, infrastructure effects, and building effects. Environmental effects affect the environment and reduce its ability to provide ecosystem services. Infrastructure effects affect hard services of the area such as movement networks, communication, water supply, and energy systems, among others, which are referred to as 'risk-reducing infrastructure' by Revi et al. (2014). Building effects affect the ability of a building to provide comfort and affect the building performance in the case of climate change impacts. These effects and possible risks were identified specifically for the context of Eswatini, and they are claimed to be caused by extreme heat, flooding, drought, and storms.

These concerns arise from the fact that these impacts are continuously degrading the valued attributes of these informal settlements and therefore affecting the function of the settlements. The valued attributes can be referred to as the key elements which keep an informal settlement functional. Effects on these elements may cause the settlement to malfunction. The identified valued attributes (derived from interviews) of an informal settlement which should be kept functional include clean water, energy, communication, movement, wellbeing, comfort, safety, affordability, ecosystem services and biodiversity, and food and waste management.

Following the identification of climate change risks on informal settlements, a study was conducted to assess the resilience of a selected informal settlement, Msunduza, located in Mbabane, Eswatini. This study area provided an opportunity to identify areas and components of the settlement which are vulnerable and those which are resilient to the risks of climate change. The assessment therefore had a focus on understanding the adaptive capacity of informal settlements in Eswatini. This part of the study identified areas with good adaptation to climate change and areas that require restoration and enhancement. There were opportunities for creating climate change resilience through nature-based solutions, which are also believed to be affordable and relevant to informal settlements. The vulnerabilities framed the design strategies to address only the resilience of components responsible for responding to the identified risks.

The next step towards determining design strategies of informal settlements towards adaptation to climate change was to conduct a precedent study. There are existing approaches to climate change adaptation that were implemented to address vulnerabilities similar to those identified in the resilience assessment of the selected informal settlement. The precedent study was conducted to learn how other experts have addressed climate change impacts to keep settlements and buildings functional and thriving. Precedent studies conducted in this study offered an opportunity to learn from practitioners about the technologies employed in their projects. Interviews with local experts also offered solutions based on the local contextual conditions. Findings from the assessment of the precedent studies and expert interviews were generally green building technologies which were not necessarily addressing resilience in some instances. However, their combination has the potential of creating a resilient system, and they were therefore documented to inform the toolkit of design strategies of informal settlements, which is the output of this study.

The results from these objectives provided sufficient data to propose design strategies that can increase the adaptive capacity of settlements. Synthesis of the results (Table 8.1) gave guidance on the response required to sustain each valued attribute and identify the component which should respond and how it should respond for a selected vulnerable area. For instance, to sustain clean water, water management systems should adapt to the risks of climate change on infrastructure and buildings. The adaptive capacity of water supply systems in informal settlements in Eswatini is poor due to the existence of a centralised water supply system with no alternative system that can act as a backup in the event the centralised system is affected by the impacts of climate change. This makes this component of the informal settlements vulnerable to climate change impacts. An existing solution to this vulnerability includes employment of water absorption/retention and water supply technologies such as rainwater harvesting tanks, water reservoirs, boreholes, and underground tanks. However, the emphasis of these solutions from precedent studies are not on ensuring redundancy/alternative sources. The strategies to be presented in this chapter address that aspect. Table 8.1 presents a synthesis of all the results from the first three sub research questions and should be understood as per the example given about water management systems. The last column presents only solutions identified from the precedent study and interviews. It is acknowledged that there could be other solutions that could work to increase the adaptive capacity of the identified components.

The following sections present the proposed strategies that should meet the criteria developed through synthesis of the results from the first three sub research questions.

Table 8.1. Synthesis of findings

1] Risks	Valued attributes	Component	2] Adaptive Capacity Status/ Vulnerability	3] Solutions found in the precedents
Infrastructure Impacts	Clean water	Water management systems	**Poor**: Centralised water supply system with no response diversity/backup systems **Poor**: Lack of alternative water management systems to reduce run-offs. Well vegetated.	**Water sources** - rainwater harvesting tanks, water reservoirs, boreholes, underground tanks. **Water management systems** - retention basin, green area, swale, underground water tanks
	Energy	Energy management systems	**Poor:** Centralised energy system with no response diversity/backup systems	**Energy sources** – centralised electricity from the grid, micro grid, small scale power generation systems (e.g. solar panels)
	Communication	Communication systems	**Poor**: Mobile communication system only	-
	Movement	Roads and footpaths	**Poor**: Poor connection of road and footpath network. Few access points leading to poor modularity.	-
	Wellbeing [health]	Heat management systems	**Average:** The southern part of the settlement has a mix of vegetation, wetlands, and a natural stream. The northern part has poor response diversity to extreme heat.	**Green infrastructure** Open spaces, cooling reservoirs, wetlands
Building Impacts	Comfort and wellbeing	Heat management systems	**Average:** Market place, public sitting area and kiosks have good adaptation to extreme heat. Most typologies have poor adaptation - one or no component responding to overheating.	**Planning**: proper orientation (windows facing north - south), mixed use development, careful spacing of buildings to allow for free flow of air **Building envelope**: building components providing shade, reflection of radiation (walls), building insulation, local and affordable materials, non-heat conductive materials **Passive and mechanical ventilation technologies** -opposite windows, narrow buildings, ventilation chimneys, perforated walls, perforated doors and windows, elevated earthen floors **Flexibility** - reconfigurable elements, configurable windows, modular system, adjustable wall thicknesses, moveable interior walls, flexible building

1] Risks	Valued attributes	Component	2] Adaptive Capacity Status/ Vulnerability	3] Solutions found in the precedents
		Water management systems	**Poor:** Few houses with water collection systems	**Water collection** - water tanks, rainwater gardens, gutter system **Building envelope** - waterproof plaster, steep roof, blue-green roofs, stone foundation **Amphibious** - stand on stilts, prefabricated floating system, light materials.
	Safety	Wind management systems	**Poo**r: Windbreak provided by trees. Buildings are not designed to adapt to strong winds.	**Windbreak**- trees, louvres, scattered planning to cut wind flow. **Wind diversion** - steep roof **Structural integrity** - strong corner posts, local materials
	Affordability	Material	**Average:** Diversity in building typology, however concrete blocks with metal roofs dominate.	**Local materials** - bamboo, earth floors, fired bricks, thatched roofing
	Clean water	Water supply systems	**Poor**: No backup systems	**Water harvesting system -** water tanks, gutter systems
	Energy	Energy supply systems	**Poor**: No backup systems	**Diverse energy sources** - photovoltaic cells, solar panels, electricity from grid, firewood
Environmental impacts	Ecosystem services and Biodiversity	Green networks	**Average**: High coverage of vegetation. Wetlands and streams identified; however, ecosystems are under threat due to densification and pollution	**Biodiversity** – planting trees, conserve vegetation, green patios, replace cut trees
	Food	Food systems	**Poor**: Majority of houses have fruit trees, but a minority has vegetable gardensFew shops and kiosks identified	**Agricultural production**
	Waste disposal	Waste management systems	**Poor**: Sparse distribution of dumpsters Informal unregulated landfills	**Sustainable waste management**: biodigester, and ecological sanitation technology

8.3. Proposed Design Strategies for Informal Settlements

The design strategies for informal settlements were developed considering all the findings of this study. The strategies are classified as follows: design strategies for buildings, design strategies for infrastructure, and design strategies for resources. Each classification consists of adaptation strategies to manage flooding, extreme heat, and storms.

8.3.1. Design strategies for buildings

Climate change risks to buildings in informal settlements include washing away of buildings by floods, blowing away of roof coverings, and poor structural and thermal performance of buildings. The risks to informal settlements offer opportunities for improving these areas while addressing their vulnerability. This section illustrates several strategies that can be considered by developers in adapting to extreme temperatures, floods, and storms at the building scale.

The subsections below summarise the design strategies that can be considered to increase the adaptive capacity of buildings to climate change within informal settlements, which can also be transferred to buildings in similar residential neighbourhoods. The strategies are categorised according to the effects of climate change to which buildings, infrastructure, and resources should adapt.

8.3.1.1. Design strategies for buildings addressing extreme heat

There are four design strategies for informal settlement buildings that were determined to be relevant for this context: diversity of solar/radiation control technologies, redundancy of passive ventilation technologies, diversity of approaches addressing heat gain, and flexibility of building envelope. These strategies consist of a mix of relevant technologies (identified from precedents and interviews) that can be implemented to improve the capacity of the buildings to adapt to extreme heat. The strategies and technologies are discussed below and summarised in Table 8.2.

- *Diversity of solar/radiation control technologies*

Buildings can be designed to control radiation from the sun through employment of several design technologies. The technologies keep the interior of the building comfortable and further reduce the cooling energy consumption of buildings. Such technologies include using reflective paint for walls and roofing (cool roofs) to reflect the sun’s radiation back to the atmosphere. Another method of controlling radiation is orienting the building such that the windows are orientated to the north or south in the southern hemisphere. The direction that a house faces affects the amount of sunlight it receives, and therefore the heat load. This, in turn, affects energy efficiency, heating and cooling costs, home maintenance, and energy flow. The goal in this case is to reduce energy absorption (and thus heat), and energy costs to improve its affordability. Long overhangs may provide shading to patios and walls to reduce internal heat gain of the rooms. The combination of all these diverse technologies (or other similar technologies) helps to improve adaptation of buildings to extreme heat.

- *Response diversity of passive ventilation technologies*

Passive ventilation is the most affordable cooling technique for homes available to informal settlement dwellers. There are different alternatives to passive ventilation which can be used in case one fails. Designing buildings to be one-room width allows for ease of cross ventilation as windows can be easily placed opposite each other. However, this may not be possible in some sites due to the size and shape of the site and the need for internal circulation. Ventilation chimneys can be used to let fresh and cooling air in the house, and they can also be used to remove the dirty air (exhaust) from the house. Another alternative is the use of perforations in walls to enable free flow of air into the building for cooling purposes. Combining different passive ventilation and cooling techniques can improve the resilience of buildings to extreme heat.

- *Response diversity of approaches to control heat gain*

Approaches that control heat gain refer to the installations which inhibit heat transfer between the outdoor and indoor spaces. Such installations in buildings prevent overheating in summer resulting in more comfortable indoor temperatures. Indoor heat gain can be reduced by the installation of ceilings, especially in buildings with metal sheet roof covering. The air gap between the ceilings and roof covering helps to reduce heat transfer into the living spaces. Secondly, using local non heat conductive and high thermal mass materials for the building envelope is an affordable method to reduce heat gain. Such materials may include adobe, rammed earth, or stone. However, the use of high thermal mass materials should be carefully considered since they could be a ‘death trap’ during heat waves. During night hours, buildings that have used these materials may take a long time to lose heat slowly gained during the day, resulting in uncomfortable night time interior temperatures. Other cooling technologies should be implemented to complement this technology.

Green roofs present another alternative for reducing heat gain in buildings. Green roofs are vegetated rooftops which can provide shade, remove heat from the air, and reduce temperatures of the roof surface and surrounding air. Using green roofs in cities or other built environments with limited vegetation can moderate the heat island effect, particularly during the day. Green roofs also provide an opportunity for growing vegetables, contributing to food security in informal settlements.

- *Flexible building envelope (transformation)*

A flexible building, in this context, allows for reconfiguration of the building elements to allow for different functions of the building to occur. Operable windows, for instance, allow the user to open them to a certain angle to capture and direct wind that can cool the internal building space in hot weather conditions. Wall thicknesses, if flexible, can be adjusted by occupants by adding or removing a wall layer to adjust the thermal insulation of the building, depending on the desired internal room temperature. Moveable interior walls can be removed in hot weather conditions to improve passive ventilation. In the case of a modular moveable system, the whole building can be moved to a different, cooler site in the case of unbearable climatic conditions. Flexibility of the building may also respond positively to flooding and storms.

8.3.1.2. Design strategies for buildings addressing flooding

There are three strategies that were identified which can be implemented in informal settlements to increase their adaptive capacity to flooding: diversity of water collection technologies, waterproofing, and flexible building. These strategies also consist of a mix of technologies which allows for the development of increased adaptive capacity of buildings to flooding. The following points discuss the strategies, as well as the possible technologies which can be implemented.

- *Response diversity of water collection technologies*

The functional diversity of water collection technologies allows for this service to be resilient and contribute to managing flooding through retention of rainwater to limit water runoffs that end up flooding buildings, infrastructure, and rivers. At building level, gutter systems which connect to water tanks can be installed. Gutter systems collect water from the roof cover and direct it to the water tank to reduce water that can flood and possibly erode the yard. This water can further be used in the building and yard for irrigation purposes in case the main water supply system is affected by natural disasters. In addition, rainwater gardens, which are sometimes called bioretention facilities, can be implemented in the yard of the building to increase rain runoff reabsorption by the soil. Rainwater running off roofs and hard surfaces is diverted to the rainwater gardens. The water in the rainwater garden is taken up by the plants or is captured in underground aquifers. A range of water collection technologies on site can ensure resilience of the water management systems to continuously address flooding within building premises.

- *Response diversity of waterproofing technologies*

One of the strategies that is proposed to increase the adaptive capacity of informal settlements to flooding is employing different affordable waterproofing technologies. This may include water resistant materials for flooring, walls, doors, windows, and ceilings. These could be diverse materials that have low water absorption capacity. Blue-green roofs can also contribute to preventing flood water from getting into the internal space of the building. This is a system that blends blue and green roof technologies. Blue roofs are designed to store rainwater which can mitigate runoff impacts and reduce flow rates from the roofs. Blue roofs can make up the drainage and support layer for green roofs which use up the water and also cool buildings. Furthermore, steep roofs can be used to drive rainwater off roofs and keep the roof dry. This prevents mould from building up in the roofs.

- *Flexible building*

Flexible buildings may allow removal of interior walls to improve ventilation which could help in drying out the building and reducing moisture which can develop mould. Modular buildings which can be easily assembled and disassembled using light natural materials reduce harm to occupants of the buildings in the event the building collapses, and further allows for easy replacement of affected components of the building.

The combination of the discussed different design strategies in buildings improve the resilience of buildings to flooding as they address different aspects of the building.

8.3.1.3. Designs strategies for buildings addressing storms

- *Diversity of wind management systems*

Buildings can adapt to storms through employing diverse wind management technologies. Trees planted around buildings can help in decreasing wind power that can affect the building. The use of steep roofs facing prevailing winds can divert winds and prevent roof uplift. Parapet walls limit exposure of roofs to strong winds. Short roof overhangs reduce the surface area exposed to winds to prevent the winds from blowing off the roof of a building.

Table 8.2. Design strategies of buildings - managing extreme heat, flooding, drought, and storms

Goal	Responding component	Strategy	Description
		1. Managing extreme heat	
I. Ensure building comfort, health and wellbeing of residents.	Building form	1.1. Diversity of solar/radiation control	• windows oriented along the north-south axis. • long roof overhangs providing complete shading to the windows and walls. • reflective paint for walls and roofing
	Ventilation system	1.2. Redundancy of passive ventilation technologies	• narrow (one room width) with windows opposite each other to ensure cross ventilation. • spacing in between buildings should not be less than 3 metres as per local building regulations to ensure air circulation. • ventilation chimneys • perforated walls • perforated doors and windows
	Building envelope	1.3. Diversity of approaches to control heat gain	• buildings with metal roof sheets should have ceilings. • use local, non-heat conductive materials, i.e. bamboo, wood shingles • use local, high thermal mass materials, i.e., fired clay bricks, stones and adobe. • green and cool roofs
		1.4. Flexible building envelope	• reconfigurable building elements - reconfigurable windows, modular system, adjustable wall thicknesses, moveable interior walls
	Site context	1.5. Building site cooling	• water fountains (evaporative cooling) • vegetation/trees
		2. Managing flooding	
II. Provision of clean water, shelter, wellbeing and safety of occupants	Water management systems	2.1. Diversity of water collection technologies	• gutter system and water tanks • rainwater gardens
	Building envelope	2.2. Diversity of waterproofing technologies	• flood resilient materials i.e., waterproof plaster • blue-green roofs • steep roofing (as per manufacturers' requirements) • elevate the floor of the house
	Building structure	2.3. Flexible building	• removable interior walls • removable fittings

Goal	Responding component	Strategy	Description
		3. Managing storms	
III. Ensure building structural integrity and safety of occupants	Building site and envelope	3.1. Diversity of wind management systems	● plant or retain trees around buildings ● steep roof facing prevailing wind direction ● parapet walls ● building orientation cognisant of prevailing winds ● short roof overhangs on side facing prevailing winds ● roof covering should be secured adequately as per roofing requirements

8.3.2. Design strategies for infrastructure

The risk of climate change on infrastructure as identified earlier in the study are the effects on road networks caused by extreme heat, erosion of bridges caused by flooding, and disturbances of power and communication networks caused by storms. The design strategies of infrastructure are expected to adapt to those climate change effects. This section presents several strategies that can be considered by developers in adapting to extreme temperatures to counteract the urban heat island effect at neighbourhood level, adapting to flooding, and adapting to storms. In this section the strategies are also grouped into three subsections: design strategies of infrastructure to adapt to a) extreme heat, b) flooding, and c) storms. The following subsections describe the strategies.

8.3.2.1. Design strategies for infrastructure addressing extreme heat

- *Response diversity of cooling technologies*

The first cooling technique that could be used to cool down buildings is evaporative cooling. Evaporative cooling uses the sunlight to evaporate water and thus remove heat and lower the temperature of the air to be used for cooling. Water features, man-made and natural wetlands, and natural streams should be incorporated in the planning and upgrading of informal settlements to cool the areas closer to these water bodies through evaporation. The air cooled down by nearby water bodies can be sucked into the buildings as part of either cross or stack ventilation. Creating public open spaces between buildings can also help in keeping informal settlements cool during heat waves and avoid health issues such as cardiovascular and respiratory disease. Tree canopy cover and, to a lesser extent, grass cover can reduce local daytime surface temperatures during extreme heat events. This could be achieved by enlarging the street tree canopy, replacing paved surfaces with trees, and providing parks and pockets of green sitting areas within the informal settlements. Diversity of tree species will ensure the survival of the green infrastructure to maintain its function of cooling these settlements.

8.3.2.2. Design strategies for infrastructure addressing flooding

- *Response diversity of water management technologies*

A diversity of water management technologies such as increased permeability/water infiltration and water attenuation/storage can improve the adaptive capacity of an informal settlement to flooding. Permeability of the ground surface can be increased by using porous pavements, and replacing concrete surfaces with green cover to reduce runoffs that can negatively impact the settlement. Water attenuation can include the use of rainwater gardens and natural water attenuation basins to retain flood water and prevent damage to buildings, infrastructure, and resources. Further to that, flood walls can be positioned to prevent encroachment of floodwater, especially close to buildings built near or even within floodplains.

- *Regenerate waterways*

Waterways in informal settlements are normally polluted, damaged or insufficient in the case of stormwater drains, limiting them from addressing flooding. This calls for regeneration of such waterways. Rivers, swamps, and flood pathways require frequent cleaning and maintenance, a process that could be best handled by the residents and local municipalities of affected areas. Some storm drains are too small to handle the current and future floods, and that requires them to be replaced with wider storm drains to increase their capacity to handle current and predicted floods. Sewer systems are sometimes flooded with water during heavy storms, and that requires them to be retrofitted with one-way valves.

- *Redundancy/alternative water sources*

The centralised water network which supplies the settlement with water may be affected by heavy rainfall which can also limit access to certain areas to address water problems. This calls for decentralised water systems and alternative water sources. A distributed network of community water tanks and taps can provide an alternative water supply solution to informal settlement dwellers. Further, community boreholes can ensure continuous water supply. The existence of alternative water supply sources can improve resilience of the water supply systems to keep the settlement supplied with water even during heavy flooding events.

8.3.2.3. Design strategies for infrastructure addressing storms

The assessment of informal settlements identified two systems that are affected which require adaptation to storms: energy systems and communication systems.

- *Redundancy/alternative energy systems*

Energy systems were identified to be centralised at Msunduza, which makes such systems vulnerable to storms. Alternative energy systems that can be used to increase the adaptive capacity of this system to storms include community solar panels, photovoltaic panels, wind power, and microgrid systems. The redundancy of these systems ensures that if one system fails due to heavy storms, another alternative power source will act as a backup to ensure some level of energy supply to households.

- *Alternative communication systems*

Communication systems such as telephone networks and mobile phone network towers are two available options that can be implemented in informal settlements to create resilience of the system to storms. Two-way radio waves could be an alternative for community members responsible for emergency services.

The proposed design strategies of infrastructure to adapt to extreme heat, flooding, and storms are presented and summarised in Table 8.3.

Table 8.3. Design strategies of infrastructure - managing heat, flooding, storms and drought

Component	**Strategy**	**Description**
	1. Managing heat	
Water collection and green infrastructure	1.1. Diversity of cooling technologies	-use open water and water features/ponds -incorporate wetlands and streams -open spaces/outdoor areas -plant different tree species -plant street trees
	2. Managing flooding	
Ground cover	2.1. Increase permeability/water infiltration	-porous pavers
Water retaining systems	2.2. Water attenuation and storage	-use green space to retain water - rainwater gardens
Waterways	2.3. Regenerate waterways	-clean waterways such as rivers and swamps (solid waste) -managing flood pathways to cope with heavy rainfall events -widening drains to increase capacity/ sustainable drain systems -one-way valves
Flood barriers	2.4. Develop flood barriers	-flood walls
Water supply systems	2.5. Redundancy/ alternative water sources	- rainwater harvesting, water reservoirs (water tanks), boreholes
	3. Managing storms	
Energy systems	3.1. Redundancy/ alternative energy systems	-power generator, solar panels, photovoltaic panels, solar geysers, village firewood, electricity from the grid -generate more energy than consumed by the building
Communication systems	3.2. Alternative communication systems	**Redundancy:** fixed telephone network, mobile phone network towers, two-way radios

8.3.3. Design strategies for resources in managing extreme heat, flooding and storms

The natural environment which keeps the informal settlements functional have been observed to be degrading due to the impacts of climate change. The climate change risks on resources include soil failure, soil erosion, and invasive species. The design strategies devised for this category address extreme heat, flooding, and storms impacts collectively. These strategies include improvement of biodiversity, improving food systems, and ensuring response diversity of waste disposal systems.

- *Encourage biodiversity*

Biodiversity can support efforts of the natural environment to adapt to climate change therefore it needs to be encouraged. Different species respond differently to extreme heat, flooding, and storms, resulting in the survival of the natural system. To encourage biodiversity, different plant/animal species can be planned in parks, pockets of green areas within the settlement, along roads, and within building premises. This would help in sustaining healthy ecosystems which provide ecosystem services to humans. Biodiversity supports efforts to reduce the negative effects of climate change.

- *Improve food systems*

Climate change affects food security within informal settlements, making it difficult to produce or provide food. Diversity of food systems improves its adaptive capacity to climate change effects. Food systems that can be implemented include small-scale agricultural production such as food gardens and food forests, kiosks, vegetable markets, and grocery shops, across the whole informal settlement.

- *Diverse waste disposal systems*

Waste disposal systems cannot be left out in the adaptation of informal settlements to climate change effects. Waste in informal settlements has been found to block storm drain channels, resulting in flooding of these settlements. A variety of waste disposal systems would offer a variety of responses to properly manage waste which ends up affecting drainage systems in informal settlements as identified at Msunduza. They include dumpsters effectively distributed across the settlements, the use of small bins strategically positioned in busy areas, and the addition of more recycle centres. Organic solid waste can be used as compost and to generate energy as observed in some precedents.

Table 8.4. presents a summary of design strategies for resources to extreme temperature, flooding and storms.

Table 8.4. Design strategies of resources for managing heat, flooding, storms and drought

Component	Strategy	Description
Flora and fauna	1.1. Encourage biodiversity	-plant different tree and vegetation species
Food systems	1.2. Improve food systems	- small-scale agricultural production - kiosks, vegetable market, grocery shops
Waste disposal components	1.3. Diverse waste disposal system	-dumpsters -bins -recycle centre

8.4. Evaluation of design strategies

The proposed design strategies for buildings, infrastructure, and resources (Table 8.5) were further evaluated through a survey and focus groups with experienced professionals and academics drawn from several relevant fields such as Architecture, Engineering, Town Planning, and Environmental Health. The aim of this exercise was to receive feedback on how suitable the identified design strategies are for the Eswatini context, and their appropriateness for the intended goal which is to keep informal settlements in Eswatini functioning normally despite experiencing climate change effects such as extreme heat, flooding, storms, and drought.

Prior to the focus group discussions, the participants were asked to evaluate the strategies using provided criteria. This survey was conducted to ensure the participants familiarise themselves with the strategies since the list of strategies was too long to cover in any depth within the focus group discussions. Another purpose was to get individual views about the strategies without the influence of other participants' opinions. The design strategies were later presented to the focus groups by the moderator (researcher) and a discussion was conducted about each strategy. The deliberations were recorded and analysed, and the input from the discussions were incorporated in the development of the final toolkit of design strategies. The brief results of the survey and focus groups are presented in the following sections.

8.4.1. Evaluation through a survey

The first step in the evaluation was to measure the suitability of the design strategies to the context of informal settlements in Eswatini. The participants were given the list of strategies individually before the focus group discussions and asked to rate each strategy according to a set of criteria. A Likert (5 point: very high, high, neutral, low, and very low) scale was used to evaluate the suitability of the strategies. Suitability was measured based on the constructability, affordability, acceptability, regulatory, and effectiveness of each strategy. These criteria were developed based on the results from all preceding sub research questions. A brief description of each term is presented in the next subsections, and a written explanation of the terms was also provided to participants to ensure they understand what they were required to rate.

- *Constructability*

Constructability is understood as the use of construction knowledge and experience in the conceptual planning, detail engineering, procurement, and field operations phases to achieve the overall project objectives (CII, 1986). This term has also been defined as the extent to which decisions made during the planning phase contribute to ease of construction (CII Australia, 1993). Constructability embraces conceptual planning, procurement design, construction, and maintenance (Griffith & Sidwell, 1995:2). In this study, however, constructability refers to how easy the proposed strategies would be to construct in the context of informal settlements, with the understanding that the buildings are self-constructed by residents, and infrastructure is developed by government or NGOs. 'High' rating means the strategy would be easily implemented on a construction site without compromising quality and building requirements.

- *Affordability*

The escalating costs of construction limits access to housing by a majority of the population living in urban areas (Sultan & Kajewski, 2003). This requires employing cost-effective solutions which can lower construction costs to be affordable to everyone. This is one of the major issues identified in the Agenda 21 for Sustainable Construction in Developing Countries (CIB/UNEP-IETC, 2002).

The concept of affordable housing is diverse and complex, and it has been generally described in economic terms (Stone, 2006): a house which a family group can acquire within a certain period, which generally ranges from 15 to 30 years. This period came about through determining the acquisition capacity of the group and the financial support that they can obtain in terms of loans, credits, and subsidies. Affordable housing has also been defined as housing that costs less than 200 USD/m^2 to produce, including the costs associated with construction and finishing details. In the context of Eswatini, the residents living in informal settlements belong to the low-income group who, if employed, receive a minimum wage of 65 USD per month. Such residents can only afford to build self-help housing using locally acquired and made building materials incrementally, and affordability was considered in the context. Rating 'Very high' affordability therefore meant that the strategy could be implemented using locally acquired/made materials and could be self-implemented by residents instead of getting paid labour.

- *Acceptability*

Acceptability is understood as the way an intervention is welcomed by the residents of the area of concern, and the extent to which the needs of the residents are met by the intervention (Ayala & Elder, 2011). Acceptance, acceptability, social acceptance, public support, social support, etc. are terms which are used to describe a similar phenomenon. The strategies should be well received by residents and authorities to be suitable for the context.

The rating of 'acceptability' considers whether the design strategies would gain crucial support from informal settlement dwellers and local authorities, or whether it will lead to opposition or criticism. 'Acceptance' further determined how well stakeholders receive and consider building resilience attributes in their designs. For instance, acceptance that residents should build redundancy of power generation to have backup in the event one of the systems fails.

- *Regulatory*

Regulatory means the extent to which the strategy can be adopted by regulatory authorities with which compliance is mandatory. Strategies that cannot be accepted by regulatory authorities are deemed unsuitable for the context.

- *Effectiveness*

An effectiveness measurement is a metric that assesses the ability of a system to meet the needs of a particular condition. Effectiveness aligns with primary goals which in the context of the study is to keep informal settlements functional even under disturbances from climate change effects. How well each individual strategy can contribute toward reaching that specific goal is what participants measured.

8.4.2. Analysis of survey

The aim of the quantitative evaluation of the strategies was mainly for purposes of ensuring that the participants deeply think about and familiarise themselves with each strategy so that the discussion in the focus group would be effective. The individual evaluations were also considered as presented in the following paragraphs. However, due to the small sample size, the study does not only depend on the results from the survey.

The survey was analysed quantitatively through finding the central tendency. This was conducted manually by finding the mode for each strategy. A mode is understood as the statistical measure which identifies a single value as a representative of an entire distribution. After all participants had evaluated the list of strategies, all the forms were collected and the mode for all the Likert scores for each strategy were sought across all the variables using all the forms. For instance, if eight participants rated constructability of a strategy as '5', and one participant rated constructability of the same strategy as '1', the mode or final rating given would be '5'. The results are presented in Table 8.5. The strategies highlighted in orange in the table are those generally showing a very low rating with modes which are 1 and 2 and needed to be considered for discussion in the focus groups to understand the reasons behind the low ratings. These are the strategies which participants considered less suitable for the Eswatini context. The strategies highlighted in green were considered more suitable for the context of informal settlements in Eswatini as they were showing high ratings of 4 and 5. The strategies which are not highlighted are considered average in rating. They were only considered suitable for the context of Eswatini after the focus group discussions.

Based on the evaluation, all the strategies are effective as the rating (mode) of their effectiveness was either 4 (high) or 5 (very high). This explains why they have been used in different precedents, as analysed in Chapter 7. The results further show that the experts that were interviewed understood the context and therefore suggested effective solutions. However, the results also present a concern about the affordability of the strategies, especially to the residents of informal settlements. Such was expected as these areas are occupied by the urban poor (Bredenoord, 2016) who might not have the ability to implement some of the strategies.

Concerns of affordability were observed mainly for strategies addressing extreme heat through building a flexible building envelope, such as adjustable wall thicknesses, moveable interior walls, and mobile houses. The affordability of the same strategies was rated low in addressing flooding. Other affordability concerns are observed in building redundancy of energy supply systems such as the use of power generators, micro grid and biodigester to generate energy. Building redundancy is expected to be costly to informal settlement dwellers since the residents must develop extra/backup solutions for use possibly only when the main system fails. Residents may have difficulty in accepting such strategies as evidenced by the low acceptability rating of the energy supply systems.

There was generally a low rating when it came to the strategies under the flexible building envelope. Therefore, the results show a low suitability of these strategies in adapting buildings to extreme heat and flooding; however, the strategies were evaluated as being effective. These are seen to be expensive strategies for the residents who self-build their houses and there is a feeling that the strategies will not be very acceptable to the residents. One of the reasons might be the fact that these are strategies which are not common in the context of Eswatini, and therefore the participants may have had difficulty in accepting them.

The limitation of a quantitative analysis is the fact that the reasons behind the ratings are unknown. The focus group discussions revealed the reasons for the low ratings of some of the strategies and further presented possible solutions. This short quantitative study complements and validates the focus group discussions as presented in the following section.

Table 8.5. Results of Evaluation of Design Strategies

Category	Strategy	Constructability	Affordability	Acceptability	Regulatory	Effectiveness
1. Buildings	**1.1. Extreme heat management**					
	1.1.1. Diversity of solar/radiation control					
	• *Windows oriented to the north-south*	5	5	5	5	5
	• *Long roof overhangs providing shading to windows and walls*	5	3	5	5	5
	• *Reflective paint for walls and roofing (cool roofs)*	5	3	5	5	5
	1.1.2. Redundancy of passive ventilation technologies					
	• *One-room width buildings with opposite windows*	5	5	4	5	5
	• *Ventilation chimneys/ shafts*	5	3	3	5	5
	• *Perforation on walls*	5	5	2	4	5
	• *Perforation on doors and windows (allow air access even when closed)*	4	2	2	5	5
	1.1.3. Diversity of approaches to control heat gain					
	• *Install ceilings in buildings roofed with metal sheets*	5	3	5	5	5
	• *Local and high thermal mass materials e.g., fired clay bricks, bamboo, wood shingles, adobe mud bricks, etc.*	5	3	4	5	5
	• *green roofs*	5	2	3	5	4
	1.1.4. Flexible building envelope (transformation)					
	• *operable windows (not fixed)*	5	2	5	5	5
	• *mobile houses*	3	1	2	1	5
	• *adjustable wall thicknesses*	1	1	1	1	3
	• *moveable interior walls*	1	1	1	1	4

Category	Strategy	Constructability	Affordability	Acceptability	Regulatory	Effectiveness
	1.1.5. Building site cooling					
	• *water ponds/fountains (evaporative cooling)*	5	2	3	1	5
	• *yard trees*	5	5	5	5	5
	1.2. Managing flooding					
	1.2.1. Redundancy of water collection technologies					
	• *gutter system connecting to water tanks*	5	5	5	5	5
	• *rainwater gardens*	1	1	1	1	5
	1.2.2. Diversity of waterproofing technologies					
	• *water resistant building materials e.g. waterproof plaster*	5	2	4	5	4
	• *blue-green roofs*	5	1	3	5	5
	• *steep roof slope (as per manufacturers' requirements)*	5	3	4	5	5
	1.2.3. Flexible building					
	• *removable interior walls*	1	1	4	1	5
	• *removable fittings*	5	1	4	1	5
	• *building on pilotis to allow storm water to flow underneath the building*	5	1	3	4	4
	1.3. Managing storms					
	1.3.2. Diversity of wind management systems					
	• *plant, transplant or retain trees around buildings*	5	5	5	5	5
	• *steep roof cognisant of prevailing winds*	4	4	4	5	5
	• *parapet walls*	5	5	4	5	5

Category	Strategy	Constructability	Affordability	Acceptability	Regulatory	Effectiveness
	• *short roof overhangs on building sides facing prevailing winds*	5	5	5	5	5
	• *secure roof structure to beams*	5	5	5	5	5
	1.3.3. Redundancy of energy supply					
	• *use of solar panels*	1	4	5	4	4
	• *power generators*	4	1	2	1	5
	• *use of biodigester to generate energy*	2	2	2	4	3
	• *microgrid*	1	1	1	4	3
2. Infrastructure	**2.1. Managing extreme heat**					
	2.1.1. Diversity of cooling technologies					
	• *water features/ponds (evaporative cooling)*	2	1	3	5	5
	• *incorporate man-made and natural wetlands (evaporative cooling)*	5	1	3	5	5
	• *open spaces/out-door sitting areas*	5	4	5	5	5
	• *diversity of tree species*	5	5	5	5	5
	• *street tree canopy*	5	3	3	3	5
	• *replace cut trees*	5	5	5	5	5
	2.2. Managing flooding					
	2.2.1. Diversity of water management technologies					
	• *porous pavers*	4	2	4	5	5
	• *green soil cover*	5	5	5	5	5
	• *rainwater gardens*	5	2	4	2	4
	• *natural water attenuation basin/park/pond*	4	4	4	5	5

Category	Strategy	Constructability	Affordability	Acceptability	Regulatory	Effectiveness
	• *flood walls*	1	5	4	5	5
	2.2.2. Regenerate waterways					
	• *clean waterways such as rivers and swamps*	5	5	5	5	5
	• *maintenance of flood pathways*	5	5	5	4	5
	• *widen storm drains to increase capacity/sustain them*	5	5	5	4	4
	• *one-way valves in sewer systems*	3	3	5	4	5
	2.2.3. Redundancy (alternative) water supply					
	• *water reservoirs (community water tanks)*	5	3	5	5	5
	• *community boreholes*	5	5	5	5	5
	2.3. Managing storms					
	2.3.1. Redundancy/alternative energy systems					
	• *community power generators*	5	1	4	3	5
	• *community solar panels and photovoltaic panels*	5	2	5	5	5
	• *community wind turbines*	5	1	2	5	5
	• *electricity from the grid (EEC)*	5	2	5	5	5
	2.3.2. Redundancy of communication systems					
	• *fixed telephone lines*	5	1	5	5	3
	• *mobile phone network towers*	3	5	5	4	5
3. Resources	**3.1. Managing extreme heat, flooding, and storms**					
	3.1.1. Encourage biodiversity					
	• *plant different tree species along streets, parks, within homesteads, etc.*	5	5	5	5	5

Category	Strategy	Constructability	Affordability	Acceptability	Regulatory	Effectiveness
	3.1.2. Functional diversity of food systems					
	• agricultural producing	5	5	5	5	5
	• kiosks along streets	5	5	5	5	5
	• centralized vegetable marketplaces	5	5	5	5	5
	• grocery shops along streets	5	5	5	5	5
	3.1.3. Functional diversity of waste disposal systems					
	• municipality dumpsters	5	5	5	5	5
	• recycle centre	5	5	5	5	5
	• use horticulture waste as organic fertilizer	5	5	4	4	5

8.4.3. Evaluation through focus groups

Following the evaluation of the strategies, the participants were invited to discuss their findings through focus groups. Participants brought their evaluation forms to the discussions for reference. Two focus groups, with a total of 8 experienced participants in senior positions in the architecture, urban planning, academia, and environmental management professions, discussed their findings on the strategies.

Most of the strategies were regarded by both groups as very simple and effective in addressing climate change effects. Participant 1 in Group A, who is an architect engaged in low-cost housing development, raised this point of discussion stating:

> "I think most of the strategies work. I like the simplicity of the strategies because if we are talking about informal settlements, we are talking about poor people who will implement these things as a DIY (do it yourself). So, you know, it should be that simple to effect."

The other participants in the same group supported the same point. Participant 1 in Group B concurred, stating that the strategies are standard and easy to implement.

There are three main themes that arose in the thematic analysis of the discussions: design strategies of concern, barriers, and recommendations. The discussion highlighted and agreed on a few strategies that would have to be reviewed, especially the strategies that would have to be implemented by the residents at building level. Further, the discussion raised general barriers to the implementation of the strategies, and lastly brought forth recommendations which could enable the strategies to be implementable in the context of informal settlements. These themes are discussed in the following subsections.

8.4.3.1. Design strategies of concern

Building strategies for extreme heat were considered suitable for the context of informal settlements in terms of their constructability, affordability, acceptability, regulatory, and effectiveness. However, concerns were raised with regards to the strategy of using water ponds for cooling purposes. Water ponds were referred to as health hazards, as they may not be well maintained leading to the spread of waterborne diseases and breeding habitats for mosquitoes. The participant asserted that stagnant water is not encouraged in informal settlements.

Another strategy of concern was the flexible building envelope to allow for passive ventilation. Different participants mainly raised concerns of affordability in the implementation of such strategies. Participant 1 (architect) stated: "I am also not sure about the adjustable wall thicknesses on the flexible building envelopes. Theoretically it's a good idea but practically it would seem to be an expensive system to come up with." Participant 2 (environmentalist) stated: “I do not think we have much experience in that one. I haven't seen many mobile houses, not just in informal settlements, but in general. Even the ones we use in construction are imported”. The disapproval seemed to have been based on lack of exposure to such systems, which might affect the acceptability of such to residents.

The use of ventilation chimneys is also another technology which is not common in Eswatini. Participants raised a concern about their acceptability and low affordability since they seem like an additional component to a house. One participant stated that ventilation chimneys are ‘complex’ for residents of informal settlements. Several participants emphasised that residents of informal settlements only need a simple shelter to protect them from weather elements.

There were opposing views with regards to the use of ceilings. Some participants agreed that ceilings are not affordable to informal settlement residents since they are an additional component. Another view was that ceilings seem expensive in the minds of people, however there are cheap means of developing them. One participant stated that it's a very effective method and brought up an example where he was involved in a study which measured temperature before and after installation of a ceiling in a metal roofed house. He stated that the difference was huge, therefore believed that considering its effectiveness in adapting to extreme heat, such installations should be considered. The precedents had shown the use of reeds for ceilings which could be very affordable to residents of informal settlements.

Infrastructure and resource strategies were also considered relevant and effective. However, the main concern was the affordability of the infrastructure in the context of informal settlements in Eswatini. Since the country does not have informal settlement upgrading “on top of their priority list”, according to participants, the cost of infrastructure and development of resources in informal settlement is transferred to the residents who are required to pay a certain fee for tenure. This would mean even the infrastructure and resource strategies would be costly for the residents who still need to develop their self-help houses.

As much as the strategies were evaluated to be suitable for informal settlements, there are several barriers that participants highlighted which may prevent their implementation. The following subsection discusses the barriers identified.

8.3.2.2. Barriers to the implementation of the strategies

Participants identified four main barriers which need to be addressed to enable the implementation of the strategies presented.

- *Difficulty in regulating informal settlements*

One of the major challenges raised in the discussions is the issue of regulating informal settlements, which is difficult from their formation to their upgrading. Informal settlements in Eswatini, and probably in general, do not follow any guidance in their formation since the residents do not have the financial capability to comply with regulations. Participant 2 (environmentalist) stated: “It is normally not a situation of them not wanting to comply, it's normally a situation of them not having the capacity to reach the required standards”.

Climate change challenges in informal settlements are addressed when the damage has already occurred. This requires retrofitting brownfields at that time, which makes it difficult to implement and regulate because of several constraints which already exist in the brownfields, such as the space constraint discussed in the next points. Upgrading of Msunduza through the Urban Development Program was not successful in the past as residents still cannot afford to align with the building regulations. One participant stated that the municipality introduced what they termed ‘grade 2’ buildings which mixes adobe blocks and concrete blocks in an attempt to make the buildings affordable. However, there is still a large section of Msunduza which remains informal and does not adhere to the building regulations.

Another aspect of the same barrier is that of exclusion of climate change adaptation strategies in the building regulations, which means that residents do not feel compelled to include such strategies. A participant from one municipality stated: “When the buildings are scrutinised by the Municipalities, orientation is not observed. We only look if the building is within the building lines, we look at structural issues and if the building is functional.” The implementation of the proposed strategies is also expected to be difficult because of the same challenge until their inclusion in the building regulations, or any other method that would address this barrier.

- *Lack of resources to implement strategies*

Another major point discussed is that of lack of resources to implement the strategies. Participants dwelled more on discussing the affordability aspect of the strategies. Developing flexible buildings to adapt to extreme heat and flooding was considered very expensive for the residents. Same with simple strategies such as planting trees. Participants felt that residents may not afford to spend their hard-earned money to buy a specified tree instead of spending their money on food. It is the same idea also with the introduction of ventilation chimneys which seem like an extra component to the building. If its use is not well understood, this may not be accepted by the residents.

The lack of financial capability to implement the strategies changes the priorities of the residents. Residents of informal settlements prioritise having basic shelter and having food for each day. One participant stated that planting a tree is the least of their (residents) priorities. Another participant highlighted the same point about rainwater gardens stating: “I do not think these residents think about rainwater gardens. In an informal settlement the residents have unique priorities. Unless of course there is an intervention from a certain program”. The same was highlighted with regards to developing redundancy of energy systems.

The issue of lack of resources was also discussed in depth at government level. One participant who is senior at the municipality stated that: “Government says it’s not a priority to upgrade these settlements. They prioritise education and health over these upgrades.” The lack of resources by the government of Eswatini forces the priorities of the government to become health and education rather than comfort and safety of the population.

- *Space constraint/ high density*

Another discussion concerned space constraints in informal settlements which becomes a barrier to the implementation of the design strategies. The density of buildings in informal settlements is so high that there is limited space to implement some of the strategies according to the participants. One participant raised the constraint in planting trees for cooling purposes and contributing to the adaptation of these areas to strong winds and flooding. The participant stated: “In informal settlements we also have a challenge of space. These people want to use every inch of space to accommodate everything there. Maybe planting a tree is the least of their priorities which makes it difficult then to regulate.” The idea was that any strategy which will require more space might not fit, unless it occupies the same space occupied by the house.

The constraint of space also limits passive ventilation as structures that are too close to each other limit the flow of air in between the buildings. One participant, who is also a designer, stated: “...when you introduce services such as heating and cooling systems, the air does not circulate properly because there is not enough space in between the buildings for air to circulate.”

Another participant addressing the same point stated that there is no proper planning in informal settlements, so reorganising the buildings such that they are north-south facing would be a challenge because the residents are “using the limited space to make the buildings face where you can easily go out and come in.” It means the residents then opt to prioritise easy entrances that will directly link with the road nearby. The random organisation of the buildings is also visible from the map of the settlement.

- *Lack of professional advice*

Informal settlements do not seem to have access to professional advice mainly because of its affordability. One participant (environmentalist) stated: "...you find that when a resident has an interest in building, you find that there is no professional advice". Another aspect raised was that even the professionals have no capacity to assist the residents with climate adaptation strategies, since they may not be well informed on such a design approach. One participant stated that the priority of some architects is the aesthetic side of the design rather than function. A complementing comment was that some residents also prioritise the aesthetics, and they are normally concerned with the other aspects once they have occupied the house.

The overarching barrier to the implementation of the climate change adaptation strategies is their unaffordability to the residents. It is difficult to regulate building performance in informal settlements because residents cannot afford to align with the building regulations and cannot afford to obtain the professional support necessary to implement these strategies. Space constraints further hamper the implementation of strategies, mainly because residents share the limited available space. Residents do not get professional advice because they cannot afford these services. Addressing the financial limitation of the residents could potentially contribute to addressing all the other barriers.

8.4.3.3. Recommendations to enable implementation of strategies

There are several recommendations made by participants that may enable the implementation of the proposed strategies. The recommendations are discussed in the points below.

- *Modification of strategies*

There are a few suggestions that were made concerning the strategies, especially those that relate to adaptation of buildings to extreme heat and storms. The participants suggested that design strategies allowing buildings to respond to flooding should focus on adaptation to pressure from flood water runoffs rather than rising water levels. Since informal settlements in Eswatini normally sit on mountainous areas rather than in flood plains, buildings are destroyed by the pressure of runoffs downslope, as discussed in Chapter 5. One participant based on his experience stated: "In the context of the study we are concerned about protecting the structures from the rainwater and running water more than water that would pile up." The use of gutter systems which link to storm drains was emphasised to adapt the buildings to flooding.

Further, since most structures are built from earth and organic material, participants suggested long roof overhangs to protect the walls from being eroded by rainwater. The participant stated:

"...some of the buildings use adobe especially deep in Msunduza. So, they should build long overhangs to protect the walls from erosion.".

There was also a suggestion concerning adaptation to strong winds. The participants suggested converting some of the community buildings such as schools and churches into storm shelters. Instead of adapting the individual buildings to storms, the suggestion was to adapt by incorporating the storm adaptation strategies in this one central building which provides a safe haven to all residents. This suggestion aims to address the fact that most residents cannot afford to incorporate the strategies in their houses.

- *Capacity building of professionals and residents*

Participants from both focus groups suggested capacity building of professionals so that they can assist residents of informal settlements. Practitioners are not familiar with the strategies to assist the residents. It is claimed that practitioners sometimes prioritise the aesthetics of the buildings and do not address climate change adaptation.

There are clearly concerns that while proper design strategies can be made available, without educating communities on how they can be implemented, these strategies will not be beneficial. Residents also need to be capacitated with the same strategies since they self-manage the construction and improvement of their houses. One participant stated:

> "...others do not see these things (importance of climate change adaptation) with the pressure they have. They just want to move in with their families as quickly as possible…. they are normally concerned with the other aspects (climate adaptation) once they have occupied the house."

In support, another participant suggested that there should be:

> "programs which should be run by the municipality on TV or radio just to bring architects and stakeholders of the built environment to give public lectures so that people are conscious that when you want to build you should be conscious or aware of certain climate design strategies or your architect should design you a well oriented building on your site."

- *Subsidy from Municipalities or government*

Since the residents cannot afford implementation of the strategies as these may represent an additional cost, participants suggested that there should be a subsidy from the government to enable implementation. Redundancy of energy generation systems, for instance, means having an extra power generating system such as a generator or solar panels to act as a backup system. This definitely will require additional costs which residents may not afford and may even not accept. One participant stated: "What I want to add is that it is high time the government takes the issue of climate change seriously and puts it on top of her agenda even when it comes to budgeting for ministries. Every ministry should have a budget to fund climate related issues".

The issue of affordability is one of the key challenges as stated above, therefore a subsidy would help in addressing most of the barriers to the implementation of climate adaptation strategies.

- *Inclusion of adaptation strategies in building regulations*

Residents are believed to have priorities other than building resilience into their buildings. It has been stated above that the priority for residents is to have shelter to cover them from weather elements. Further, even with the formalised plots, residents do not include adaptation strategies as they are not included in the building regulations. A plan is approved even if it is facing the east-west direction, or even if it does not adapt to flooding and storms. It is therefore suggested that the proposed climate adaptation strategies should be included in the building regulations so that residents are forced to comply and build resilient buildings.

- *Research*

Research is also valued and believed to contribute to the proper implementation of adaptation strategies. One participant, who raised the recommendation of research, stated, "Then you also want to put a lot of energy on research because you need to interrogate all the strategies." The suggestion was that the strategies still need to be tested practically through pilot projects before they can be officially used as working strategies adapting to climate change effects.

In agreement, another participant stated that research can identify areas prone to natural disasters. The participant stated that these are the areas where the strategies embedded in the building regulations can be enforced.

- *Establishment of a regulatory council*

A regulatory council was also proposed to "push and educate people about the issues of climate change in Eswatini as far as buildings are concerned." The council was proposed to regulate the built environment and other industries to adapt to climate change. Such a council would enforce the proposed strategies.

The barriers and recommendations are presented in Table 8.6 below. The barriers seem to have solutions in the recommendations as matched in the table. The recommendations are considered as enablers of the proposed strategies for informal settlements.

Table 8.6. Barriers and recommendations to the implementation of design strategies for informal settlements

	Barriers	**Recommendations**
1	Difficulty in regulating informal settlements	Inclusion of adaptation strategies in buildings regulations, Establishment of a regulatory council
2	Lack of resources to implement strategies	Subsidy from Municipalities or government
3	Space constraint/ high density	Research, Modification of strategies
4	Lack of professional advice	Capacity building of professionals and residents

The evaluation of the strategies contributed to the study by eliminating strategies that are not relevant to the context of informal settlements in Eswatini, and provided insights into how the strategies can be structured to address the barriers and align with the recommendations. The strategies should be easy to enforce and should be implementable incrementally to address the major concern of affordability. The strategies should further be categorized to have strategies that can be implemented by residents, and government/organizations for the strategies considered to be expensive. The following section presents the output of the study with considerations of the input made by the experts.

8.5. Design Toolkit

Following the synthesis of the results of the first three sub questions to come up with a list of design strategies and evaluation of those design strategies by practitioners, this section presents a framework that can be followed in the development of the strategies, and a final set of design strategies suitable for informal settlements in Eswatini. These strategies have been framed by the four sub questions of the study, as discussed in Section 8.2, and this section responds to the main research question of the study: “What design strategies can be taken to improve the capacity of informal settlements in Eswatini to adapt to the impacts of climate change?”

This study makes two contributions that respond to the main research question of the study:

a) The process for developing or identifying suitable design strategies in a specific context, captured in a framework (Figure 8.1)
b) The set of design strategies developed specifically for Eswatini, captured in the design toolkit (Table 8.7).

The framework with the potential of increasing spatial resilience of informal settlements has four phases of implementation as described below:

- *Phase 1*

Climate change disasters vary in different geographical regions and climate zones, and result in a wide range of impacts across different regions and different economic sectors (World Bank, 2022). This phase therefore aims to identify climate change disasters for the region where the settlement under assessment is located. Some areas may experience strong winds, extreme heat, or extreme rainfall which may result in certain type of impacts.

- *Phase 2*

Upon identification of climate change disasters, this phase identifies the impacts to which informal settlements should adapt within the defined categories or subdimensions of infrastructure, building, and environment, which fall under the physical dimension of the settlement. The impacts are identified so that relevant actions are devised in Phase 4 for the settlement to be resilient to those impacts. For instance, resilience cannot be built in settlements to address drought impacts in an area receiving increased rainfall. The impacts relevant to each area should be identified.

- *Phase 3*

The third phase aims to identify vulnerable areas or components within the settlement to inform actions that should be taken to enhance their resilience. There are components/variables highlighted in the framework proposed for assessment. These are the components which are responsible for increasing the adaptive capacity (reducing the vulnerability) of informal settlements to meet certain sustainability goals. At this stage it is also critical to define the valued attributes or sustainable goals and barriers for their achievement. The attributes/goals may also be the targets for informal settlement upgrading. These attributes form the goal of development, and resilience becomes a pathway towards attaining those goals to keep the settlement functional. The study identified vulnerable components of informal settlements, directly linked to the valued attributes, which need to be assessed in order to determine the potential to be enhanced to increase resilience of informal settlements. The study sought the level of diversity, redundancy, connectivity, or modularity in each component to determine its adaptive capacity level.

Phase 4

The last stage proposes actions that will be relevant for the context and informal settlement under assessment to build resilience to climate change. This can be leveraged to informal settlement upgrading to prevent reversal of development gains. This is the phase which may result in the development of a design toolkit.

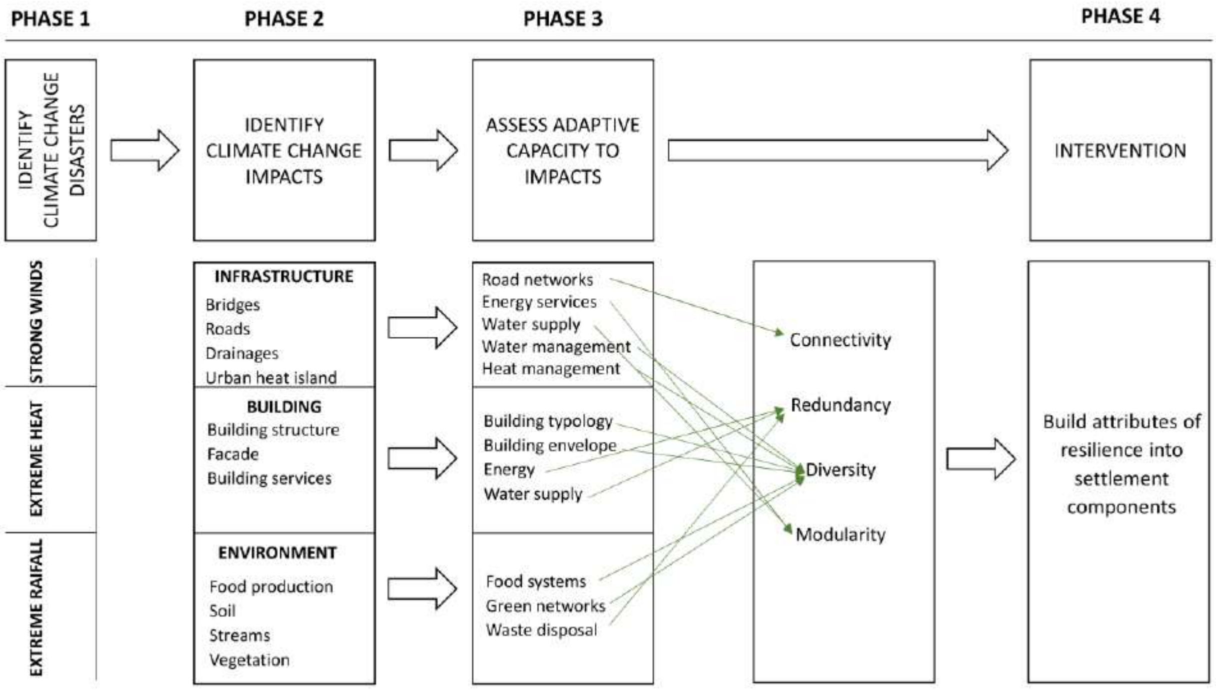


Figure 8.1. Resilience Assessment and Implementation Framework for Informal Settlements

This framework, which can be implemented in different informal settlements, was used in the context of Eswatini to come up with the design toolkit presented in Table 8.7 below. The strategies are categorised into three: strategies that can be used by residents to retrofit their buildings; strategies that can be used in formal upgrading by authorities; and strategies that can be used in new developments.

8.5.1. New developments

There are strategies that can be implemented through new projects, and these encompass all suitable strategies identified by the experts and excludes the strategies which were considered irrelevant to increase the adaptive capacity of informal settlements in Eswatini to the impacts of climate change. Strategies excluded from the original list of strategies evaluated are all the strategies highlighted in orange in Table 8.5.

In the event that informal settlers are relocated to a new site, all the strategies in this set can be implemented in the new site. New residents can also be guided through empowerment programmes to implement this set of strategies. This category is therefore the most effective as it does not limit the implementation of some strategies due to constraints posed by already existing buildings, infrastructure, and resources. The new developments can be implemented by local authorities such as the strategies categorised under infrastructure and resources, and residents can implement some of the strategies through self-help housing construction if social housing is not provided by the local authorities or government.

The set of strategies implemented through new developments can therefore be understood as a superset of the two other categories discussed below, since it includes all suitable strategies identified by the study.

8.5.2. Formal upgrading

The toolkit also provides another set of strategies which can only be implemented by local authorities, organisations, or governments, through formal informal settlement upgrading. Such strategies may be unaffordable to be implemented by the local residents, such as the strategies which relate to infrastructure. These strategies also require specialists to implement, such as widening of storm drains, which may require engineering expertise in infrastructure design. This set is a subset of the strategies implementable through new developments.

As per the suggestions of participants which evaluated the strategies, these developers would need to be capacitated to use the strategies as the professionals may not be well informed about responding to the impacts of climate change. This has been observed in several city resilience frameworks reviewed in Chapter 2, where the first stages of implementing the assessment frameworks required municipal officials to be educated on how to use the tools.

8.5.3. Retrofitting by residents

It is a possibility that most of the informal settlement residents would not afford to build resilient housing from scratch, therefore, upgrading their existing houses to adapt to the impacts of climate change is the most likely option. Even then, there are limits to what the residents can implement, and adopting an incremental approach to improvements of their houses with resilience in mind, might be a more viable solution. This set consists of strategies which can be implemented by residents to retrofit their buildings and excludes strategies which can only be implemented in a new development. This set however, is also a subset of the strategies categorised under ‘new development’ in Table 8.7. The strategies are few as they only include strategies that had a high rating of affordability and constructability. The strategies which were rated as not suitable (low rating across criteria) were excluded from this set and the other two sets.

Table 8.7 Design Toolkit for residents and formal upgrading

Category	Strategy	Retrofitting by residents	Formal upgrading	New development
1. Buildings	**1.1. Extreme heat management**			
	1.1.1. Diversity of solar/radiation control			
	• *Windows oriented to the north-south*			✓
	• *Long roof overhangs providing shading to windows and walls*	✓		✓
	• *Reflective paint for walls and roofing (cool roofs)*	✓		✓
	1.1.2. Redundancy of passive ventilation technologies			
	• *One-room width buildings with opposite windows*			✓
	• *Ventilation chimneys/ shafts*			✓
	• *Perforation on walls*	✓		✓
	• *Perforation on doors and windows (allow air access even when closed)*			✓
	1.1.3. Diversity of approaches to control heat gain			
	• *Install ceilings in buildings roofed with metal sheets*	✓		✓
	• *Local and high thermal mass materials i.e. fired clay bricks, bamboo, wood shingles, adobe mud bricks, etc.*			✓
	• *green roofs*			✓
	1.1.4. Flexible building envelope (transformation)			
	• *operable windows (not fixed)*	✓		✓
	1.1.5. Building site cooling			
	• *yard trees*	✓		✓
	1.2. Managing flooding			
	1.2.1. Redundancy of water collection technologies			
	• *gutter system connecting to water tanks*	✓		✓
	1.2.2. Diversity of waterproofing technologies			
	• *water resistant building materials e.g. waterproof plaster*			✓
	• *blue-green roofs*			✓
	• *steep roof slope (as per manufacturers' requirements)*	✓		✓
	1.2.3. Flexible building			
	• *removable fittings*	✓		✓
	1.3. Managing storms			
	1.3.2. Diversity of wind management systems			
	• *plant, transplant or retain trees around buildings*	✓		✓

Category	Strategy	Retrofitting by residents	Formal upgrading	New development
	• *steep roof cognisant of prevailing winds*	✓		✓
	• *parapet walls*			✓
	• *short roof overhangs on building sides facing prevailing winds*	✓		✓
	• *secure roof structure to beams*			✓
	1.3.3. Redundancy of energy supply			
	• *use of solar panels*	✓		✓
2. Infrastructure	**2.1. Managing extreme heat**			
	2.1.1. Diversity of cooling technologies			
	• *incorporate man-made and natural wetlands (evaporative cooling)*		✓	✓
	• *open spaces/out-door sitting areas*		✓	✓
	• *diversity of tree species*	✓	✓	✓
	• *street tree canopy*		✓	✓
	• *replace cut trees*	✓	✓	✓
	2.2. Managing flooding			
	2.2.1. Diversity of water management technologies			
	• *porous pavers*	✓		✓
	• *green soil cover*	✓	✓	✓
	• *natural water attenuation basin/park/pond*		✓	✓
	• *flood walls*		✓	✓
	2.2.2. Regenerate waterways			
	• *clean waterways such as rivers and swamps*	✓	✓	✓
	• *maintenance of flood pathways*	✓	✓	✓
	• *widen storm drains to increase capacity/sustain them*		✓	✓
	• *one-way valves in sewer systems*		✓	✓
	2.2.3. Redundancy (alternative) water supply			
	• *water reservoirs (community water tanks)*		✓	✓
	• *community boreholes*		✓	✓
	2.3. Managing storms			
	2.3.1. Redundancy/alternative energy systems			
	• *community power generators*		✓	✓
	• *community solar panels and photovoltaic panels*		✓	✓
	• *community wind turbines*		✓	✓

Category	Strategy	Retrofitting by residents	Formal upgrading	New development
	• *electricity from the grid (EEC)*		✓	✓
	2.3.2. Redundancy of communication systems			
	• *fixed telephone lines*		✓	✓
	• *mobile phone network towers*		✓	✓
3. Resources	**3.1. Managing extreme heat, flooding and storms**			
	3.1.1. Encourage biodiversity			
	• *plant different tree species along streets, parks, within homesteads, etc.*	✓	✓	✓
	3.1.2. Functional diversity of food systems			
	• *small scale agricultural producing*	✓	✓	✓
	• *kiosks along streets*	✓		✓
	• *centralized vegetable marketplaces*	✓	✓	✓
	• *grocery shops along streets*	✓	✓	✓
	3.1.3. Functional diversity of waste disposal systems			
	• *municipality dumpsters*		✓	✓
	• *recycle centre*		✓	✓
	• *use horticulture waste as organic fertilizer*	✓	✓	✓

8.6. Conclusion

The objective of this chapter was "to evaluate design strategies that can be suitable for informal settlements in Eswatini to increase their adaptive capacity to the impacts of climate change." This was achieved through evaluation of proposed strategies developed through synthesis of findings from the first three sub-objectives. The evaluated strategies informed the design toolkit which was the output of the study and responding to the main objective of the study: "to identify design strategies which can be implemented to increase the capacity of informal settlements in Eswatini and similar contexts to adapt to the impacts of climate change in order to thrive."

Relevant strategies from precedents and contributions from interviews were used to come up with a list of strategies combined to build resilience through building the characteristics of resilience into the responding components. The strategies were structured as design strategies of buildings, infrastructure, and resources. Design strategies for buildings aimed at managing extreme heat were found to be diversity of radiation control, redundancy of passive ventilation technologies, diversity of thermal insulation, flexibility of the building envelope, and building site cooling. The approach was to build resilience into the components responding to extreme heat through the use of green building technologies. In managing flooding the proposal was to develop diversity of water collection technologies, diversity of waterproofing technologies, and flexible buildings. These strategies will reduce the impacts of flood water runoffs which affect buildings. Then increasing the adaptive capacity of buildings to storms had one strategy of creating diversity of wind management systems.

There is also a need to increase the adaptive capacity of infrastructure to extreme heat, flooding, and storms as discussed in Chapter 5. The strategy proposed to ensure resilience of infrastructure to extreme heat was mainly building diversity of cooling technologies. To manage flooding there are several strategies which were proposed: increasing permeability/water infiltration, water attenuation and storage, regenerating existing waterways, developing flood barriers, and creating redundancy of water sources. Concerning adaptation to storms, developing alternative energy systems and communication systems was believed to assist in ensuring continuous functioning of power and communication systems even during heavy storms.

The last group of strategies was those ensuring a high adaptive capacity of resources to extreme heat, flooding, and storms, to ensure their survival even when faced with the effects of climate change. They include encouraging biodiversity to improve different responses to the impacts. Food systems need to be improved to ensure food security even in the times of perturbation. Diverse waste disposal systems are also proposed to keep the natural environment and infrastructure clean and enable them to address the climatic impacts.

These strategies needed to be evaluated to confirm their suitability to the context of the study (informal settlements in Eswatini). The list of strategies was compiled, and the suitability of the strategies in the context of informal settlements in Eswatini was evaluated by determining their constructability, affordability, acceptability, regulatory, and effectiveness. The building strategies meant to address extreme heat relating to flexibility were generally rated as of low suitability. Most of the strategies had a high rating of effectiveness, but the criteria of affordability and acceptability presented the most concerns. The evaluations were mainly used to get participants to familiarise themselves with the strategies before attending focus group discussions. There were two focus groups which were composed of architects, academics, environmentalists, and an urban planner. The two groups raised similar issues concerning the strategies, therefore a third discussion was not conducted as saturation was reached.

A thematic analysis of the discussions brought about three key themes which were design strategies of concern, barriers to the implementation of the strategies, and recommendations to enable the implementation of the strategies. The design strategies of concern included the flexible building strategies which participants felt were complex and not affordable to the residents of informal settlements. Participants stated that the strategies required expertise which is limited in the context of Eswatini since the strategies are not common, even in the formal part of the city. Further, the use of water ponds was labelled as a health hazard because of zero maintenance, which was anticipated. They were also believed to offer a breeding habitat for mosquitoes. Participants considered ventilation chimneys as unsuitable as they would result in additional costs, which participants might not accept.

The discussions mainly focused on the barriers to the implementation of the design strategies since the belief was that the strategies are very effective and relevant to the context; however, there were barriers which had a potential of affecting their implementation in the context of informal settlements. The barriers highlighted include difficulty in regulating informal settlements, lack of resources to implement strategies, space constraints, and lack of professional advice. Informal settlements are difficult to regulate since they are brownfields that are already out of shape, and replanning them is believed to be a challenge as the residents already accepted living in the current state. The informal settlement dwellers cannot afford to implement the strategies and they opt to prioritise building the shells just to protect themselves from weather elements. Space constraints are also believed to be challenging since some strategies require additional space, which is not available. Further, residents are believed to not engage professional advice due to its low affordability.

The discussions also provided recommendations that have the potential to enable the implementation of the strategies. The first one was the inclusion of adaptation strategies in building regulations and establishing a regulatory council. This will ensure the enforcement of the strategies to residents and further regulate their implementation. To address the main overarching barrier of lack of resources, it was recommended that the possibility of receiving subsidy from Municipalities or government should be considered so that the strategies could be implemented. Research is also valued, and it was suggested by participants to identify the most vulnerable areas to be addressed. Finally, capacity building of professionals was suggested as they might be lacking capacity to guide the residents to develop designs which adapt to climate change. The residents also need to be educated about climate change adaptation so that they consider such in their self-managed houses.

This chapter responded to the main research question of the study through presenting a design toolkit of strategies for informal settlements which have a potential to adapt to climate change effects in the context of Eswatini. The strategies are generally suitable in the context of informal settlements, however, there are enablers which need to be considered first before the strategies can be fully implemented as identified by the experts.

Chapter 9: Conclusion

9.1. Introduction

Informal settlements are claimed to experience acute impacts of climate change due to their unfavourable location, temporal shelter, lack of access to clean water, and sanitation, among other conditions (Roy et al., 2018). These areas are critical, as according to Roy et al. (2018:282), they are areas "where poverty, inequality and deprivation are concentrated in cities across the developing world". This study, therefore, investigated and proposed design strategies to improve their adaptive capacity and ensure their survival in spite of the main expected disturbances from climate change in Eswatini, namely extreme heat, flooding, drought and storms.

This study took a pragmatic approach to provide practical findings. An informal settlement, Msunduza, in Mbabane, Eswatini, was selected as a case study to explore the climate adaptation capacity of informal settlements and further propose climate change adaptation measures that can be implemented to limit climate disturbances which affect these vulnerable areas. The current condition of the selected informal settlement for study in terms of its adaptation capacity was considered through a fieldwork where the buildings, infrastructure, and resources were assessed. This exercise was preceded by an analysis of the climate condition of Eswatini, and identification of the climate change impacts which affect residential neighbourhoods, especially those occupied by the urban poor. Further, the study learnt from other projects, mostly in developing countries, how they have addressed similar challenges. All findings were synthesised to propose design strategies for informal settlements (buildings, infrastructure, and resources) addressing the identified climate change impacts enhancing the resilience and ensuring a functional settlement providing all necessary benefits for the survival of their occupants.

9.2. Summary of findings

The research project was guided by the following research question:
'What design strategies can be taken to improve the capacity of informal settlements in Eswatini to adapt to the impacts of climate change?' This question was divided into the three sub-questions and the pertinent findings for each of the sub-questions are as discussed in the following subsections.

9.2.1. Sub-question 1

Which predicted climate change impacts require an adaptive response from informal settlements in the context of Eswatini?

This research phase identified climate change impacts affecting residential neighbourhoods in Eswatini through interviews with experts involved in climate change related practices. These experts were drawn from academia, the built environment industry, municipalities and town boards, government, parastatals, and consultants. The experts identified informal settlements as the most vulnerable areas which require urgent attention to avoid their destruction. From thematic analysis of the transcribed interviews, it was identified that climate change impacts included impacts on buildings, infrastructure, and natural environment; and there were social impacts identified. These are as a result of changes in climate, which were identified by experts and confirmed by climate data from the Eswatini Meteorological services, as being an increase in average temperatures, erratic rainfall, and increase in wind pressure.

The impacts identified as social impacts refer to the kind of disturbances which affect the wellbeing of residents as a result of changes in temperature, rainfall, and wind. These include health and comfort related impacts resulting from overheating, pollution, and mould as a result of flooding. Environmental impacts are experienced as a result of soil failure, erosion, drought, and invasive species, among other effects. Infrastructure impacts on the other hand entails effects resulting mostly from high pressure winds and flooding which erodes bridges and affects roads and power lines. Lastly, building impacts refer to effects that test the structural integrity of the building as a result of extreme heat impacting the performance of buildings, high velocity water flow washing away buildings, and strong winds blowing away roof coverings, among other effects. The results created a base for the study to understand the climate change impacts that require an adaptive response from informal settlements.

9.2.2. Sub-question 2

'What is the current adaptive capacity of informal settlements in the context of Eswatini?'

Field work was conducted with the aim of identifying the adaptive capacity of informal settlements using a semi-structured observation guide. The study sought to evaluate the existence of general resilience attributes of diversity, redundancy, connectivity, and modularity to determine if selected components of the settlement are resilient to extreme heat, flooding and storms. These components which were identified to be responsible for responding to climate change impacts include, water management systems, heat management systems, energy, water supply, building envelope, waste management systems, and the natural environment.

The observations revealed that the adaptive capacity of the infrastructure to extreme heat, flooding, and storms, varies from component to component; however, it is generally low. Water management systems have a low adaptive capacity due to the lack of alternative water management systems to reduce run-offs that eventually affect houses and residents of such areas. Water supply and energy systems have centralised systems with no response diversity nor backup systems, making these systems vulnerable to the impacts of climate change. There are no telecommunication systems except the mobile phone towers. Movement systems do not represent a well-connected internal layout of vehicular roads and pedestrian paths and they are further limited to a few access points in a broader scale.

There is also a distinct geographical component to the vulnerability and adaptability of the heat management systems. Heat management systems in the southern part of the settlement adapts well to extreme heat due to the diversity of vegetation, wetlands, and the existence of a natural stream responsible for cooling this area. The northern part of the settlement, however, has poor response to extreme heat due to the low response diversity of the heat management systems, resulting in low adaptive capacity.

The results further showed that the adaptive capacity of buildings to climate change impacts is also generally low. The results showed diversity in building typology - dwelling units, row houses, kiosks, shops, and marketplace; however, the majority of the buildings are dwelling units. Heat adaptation of buildings was rated and the marketplace, public sitting area, and a percentage of kiosks were the only structures which had traces of good adaptation. Most of the typologies have poor adaptation to extreme heat, meaning they have one or no component of the building which responds to overheating. The adaptive capacity of building services is also quite low as there are no backups or redundancies in these systems at both settlement and building level. Storm water, on the other hand, is addressed by vegetation, but there are no other water management systems, and that makes the buildings vulnerable to flooding. Wind pressure is only addressed by vegetation within the premises of each homestead.

The adaptive capacity of resources namely, green networks, food systems, and waste disposal, is under threat. The increase in population and structures put more pressure on green networks which affects ecosystems. Extreme temperatures and unpredictable rainfall are a risk to these ecosystem services which can eventually affect the economy and livelihood of the residents.

The overall adaptive capacity of the informal settlement is therefore generally low; however, there are areas with traces of good adaptive capacity whose resilience would have to be enhanced. This phase of the study provided sufficient information about the adaptive capacity of the informal settlement selected for study.

9.2.3. Sub-question 3

How have other developing countries addressed the adaptation of residential settlements to climate change impacts?

The climate change responsive designs presented in Clegg and Sandeman (2019) were considered, along with several other international precedents. Eleven projects which responded to climate change were evaluated to extract lessons regarding possible adaptation strategies. The results revealed that these approaches mainly addressed extreme heat adaptation. Furthermore, the strategies mainly addressed building design, especially the building envelope, with strategies such as shading through building components, reflection of radiation, building insulation, and using local and affordable building materials. All the precedents also emphasised passive ventilation technologies such as using ventilation chimneys, perforated walls, perforated doors and windows, narrow building form, and opposing windows. A few highlighted the flexibility of a building as a design solution to address heat, such as using reconfigurable elements, modular systems, adjustable wall thicknesses, and moveable interior walls.

Since these strategies focused on heat adaptation, a further investigation was conducted by purposely selecting international precedents that address adaptation to flooding and extreme weather events. The selected projects include El Pozon, local Fiji housing, a Copenhagen flooding adaptation project, Thailand proposed amphibious houses, the lift house in Bangladesh, a community library in Sri Lanka, Earth Village in Vietnam, Jetwing Vil in Vietnam and Soneva Kiri in Thailand. Strategies used include nature-based water management, amphibious solutions, as well as water collection methods. With regards to wind adaptation, strategies mainly focused on the use of vegetation and building form to break wind pressure. Further to this, results from expert interviews revealed strategies which address building envelopes, building performance, and climate awareness as design proposals to address climate change impacts.

This phase of the study was beneficial in providing a base for developing the design strategies of informal settlements that would be further interrogated for suitability in the context of Eswatini.

9.2.3. Sub-question 4

Which design strategies can be suitable for informal settlements in Eswatini to increase their capacity to adapt to the impacts of climate change?

The findings from all sub-questions were synthesised. The results from the sub-objectives provided sufficient data to propose design strategies that can increase the capacity of informal settlements to adapt to climate change impacts. The green technologies identified through the precedent study and interviews with experts were selected to create diversity, redundancy, and modularity in the components which are expected to respond to climate change effects in a settlement. The strategies proposed were grouped into design strategies of buildings, infrastructure, and resources addressing extreme heat, flooding, and storms, as presented in Chapter 8.

The identified building strategies addressing extreme heat were the following: diversity of radiation control technologies, response diversity of passive ventilation technologies, response diversity of thermal insulation of building envelope, and flexible building envelope. Strategies aimed at increasing the adaptive capacity of buildings to flooding include: response diversity of water collection technologies, response diversity of waterproofing technologies, and flexible building. Then strategies aiming to build resilience of buildings to storms include diversity of wind management systems.

The proposed strategies aimed at improving the adaptive capacity of infrastructure to extreme heat were response diversity of cooling technologies. Strategies addressing flooding include response diversity of water management technologies, regenerate waterways, and redundancy of water sources. Then strategies aimed at increasing the adaptive capacity of infrastructure to storms were: redundancy of energy systems, and redundancy of communication systems, to ensure the continuous provision of energy and communication function even during storms.

The last category of strategies is those improving the adaptive capacity of resources to flooding, extreme heat, and storms. The proposed strategies under this category are: encourage biodiversity, improve food systems, and provide diversity of waste disposal systems.

These strategies were evaluated by practitioners through a survey to determine their suitability in the context of informal settlements in Eswatini using a Likert scale to evaluate their constructability, affordability, acceptability, regulatory, and effectiveness. Further, focus group discussions were conducted and the analysis revealed three themes: design strategies of concern, barriers to the implementation of the strategies, and recommendations to the implementation of the strategies. The design strategies of concern are those highlighted by participants that are required to be improved, such as the strategy of flexible building envelope to allow for passive ventilation and adapt to flooding. These strategies were claimed to be expensive to the residents of informal settlements, and their acceptability was doubted. Further, the use of ventilation chimneys and ceilings for cooling buildings were claimed to add costs, which may not be affordable to residents.

The barriers to the implementation of the strategies were: difficulty in regulating informal settlements, lack of resources to implement strategies, space constraints, and lack of professional advice. There were recommendations made to enable the implementation of the strategies which were: modification of some of the strategies, capacity building of professionals and residents, subsidy from municipalities or government, inclusion of adaptation strategies in building regulations, research, and establishment of a regulatory council.

9.2.4. Answering the main research question

The study asked: What design strategies can be taken to improve the capacity of informal settlements in Eswatini to adapt to the impacts of climate change?

Following the evaluation of the proposed design strategies, the output of the study was determined:

a) The process for developing or identifying suitable design strategies in a specific context, captured in a framework (Figure 8.1). This framework has four phases informed by the studies conducted to respond to each research question. Phase 1 aims to identify the climate change disasters of the geographical location or zone of the settlement under assessment. Phase 2 aims to identify the impacts to which informal settlements should adapt to function properly. Phase 3 aims to identify the vulnerable areas of informal settlements through seeking the level of diversity, redundancy, connectivity, or modularity. This approach was informed by the Resilience assessment framework by Resilience Alliance (2010) as presented in Chapter 2. Phase 4, in consideration of the other phases, aims to propose actions or strategies that will improve the adaptive capacity of informal settlements to the identified impacts of climate change.

b) The set of design strategies developed specifically for Eswatini, captured in the design toolkit (Table 8.7). The evaluation informed categorization of the design strategies to have strategies suitable for new developments, strategies suitable when used in formal upgrading of informal settlements, and strategies that can be used by residents to retrofit their existing buildings.

The designs strategies proposed as an output of the study have several contributions discussed in the following section. The strategies can also be improved as per the discussion in Section 9.4 and Section 9.5 below.

9.3. Summary of contributions

The study contributes to climate change, informal settlement upgrading, and resilience discourses. The findings and recommendations from the study can inform changes in informal settlement upgrading and resilient affordable housing development within Eswatini. The possible contribution of the climate change adaptation strategies is described in detail in the following points:

- The study contributes to the resilience discourse by developing a framework for assessing the spatial and material structure of informal settlements to determine their adaptive capacity. This framework can be further developed for use in evaluation of residential neighbourhoods and even cities to determine their adaptive capacity.
- The study further contributed to the climate change discourse by developing design strategies that can be used by practitioners in developing affordable neighbourhoods that will adapt to the effect of climate change and thrive even in the midst of disturbances. This toolkit can also be used by residents to guide them on proper affordable and climate change responsive strategies.
- The study also contributes to informal settlement upgrading and climate adaptation by identifying risks of climate change to residential neighbourhoods in the context of Eswatini. This information can create a base from which municipalities can develop strategies and policies concerning adaptation to the identified climate change risks.

9.4. Suggestions for further research

Several areas for further research were identified from this mixed method study.

a) In terms of the interviews conducted in research sub objective one, further research is to expand the group of respondents to include community residents and receive first hand data on how they are affected by climate change impacts. The proposed solutions will be more relevant in addressing the challenges faced by the communities.

b) The observations conducted in research sub objective two should be supplemented with interviews of residents to establish how they adapt to the effects of climate change. Practices of residents to ensure adaptation can be identified and enhanced. This can be an important contribution in establishing how the adaptation practices can be improved.

c) For the mapping methodologies, future research should also consider the drone-based mapping combined with collaborative mapping, as suggested by the paper: "A Hybrid Methodology to Map Informal Settlements in Durban, South Africa" (Loggia & Govender, 2019).

d) The precedent study conducted to respond to sub objective three can be further expanded through both literature analysis and other methods to increase the number of projects from which to learn. Further research can investigate practices already conducted in informal settlements or affordable housing settlements only.

e) Future studies can consider analysing more in detail the legislative and policy framework on informal settlement upgrading looking at community-led approaches to informal settlements upgrading.

f) It is suggested that future research should include the technical guidance of the European Commission on adapting buildings to climate change (European Commission, 2023).

g) Finally, further work can be done to do an in-depth review of and further develop the proposed design strategies.

9.5. Recommendations

The research project identified design strategies believed to be responsive to the climate change risks confronted by informal settlements. Unfortunately, these strategies have not been tested practically to test their effectiveness due to financial and time constraints. A pilot project is recommended to be built through a participatory approach to get to understand challenges encountered even during the construction phase. The pilot project will allow for practical measurement of the success of the strategies in the context it was designed for.

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APPENDIX A. Interview Guide – Climate Change Disturbances in Residential Neighbourhoods

1. Objective [2]: To understand the current climate change disturbances residential neighbourhoods should adapt to in order to thrive.

	Theme	Main Guiding Questions
A	General/Warm-up/Background	1. **What is your role and experience in anything related to climate change and residential neighbourhoods/ housing development or planning?** [Aiming to understand area of speciality and general views of interviewer]
B	**Changes in Temperature** [Effects of temperature changes on residential neighbourhoods]	2. **Are temperatures changing in the context of Eswatini?** Elaborate. 3. In your field of work as a specialist, what effects/disturbances have you observed in the functioning, development, management, and/or planning of residential neighbourhoods as a result of changes in temperatures? Elaborate. *i.e. effects on drainage systems or any infrastructure or building component caused by overheating or very cold weather* 4. How have you previously addressed such challenges? *i.e. or how have you seen other specialists addressing the problem?* 5. Do you foresee any future disturbances caused by future changes in temperature? Elaborate. [Aiming to understand if residential neighbourhoods in the context of Eswatini should adapt to changes in temperature]
C	**Rainfall patterns and storms** [Effects of flooding on residential neighbourhoods]	6. **Are rainfall patterns changing in the context of Eswatini?** Elaborate. 7. Have you observed any disturbances in the functioning, development, management, and/or planning of any residential neighbourhood (infrastructure and buildings) caused by the gradual change in rainfall and storms patterns as a result of climate change in the context of Eswatini? Elaborate. *i.e. you may think of the recent cyclone… what were the effects…? Decrease or increase in rainfall?* 8. How have you (or other specialists) previously addressed such effects? 9. Do you foresee any future disturbances caused by future changes in rain patterns? Elaborate. [Aiming to get understanding if residential neighbourhoods in the context of Eswatini should adapt to changes in rainfall patterns]
D	**Wind patterns** [Effects caused by strong winds]	10. **Are wind patterns changing in the context of Eswatini? Elaborate.**

		11. Are there any disturbances in the functioning and form/structure of residential neighbourhoods you believe were experienced as a result of changes in wind patterns? Elaborate on the observed disturbances. *i.e. you may think of utilities, or any infrastructure/building components that may be affected by strong wind* 12. In those events, how was the functioning of the neighbourhood restored by yourself or others? *If there was no restoration, what were the challenges?* 13. Do you foresee any future disturbances caused by future changes in wind patterns? Elaborate. [Aiming to identify if residential neighbourhoods in the context of Eswatini should adapt to changes in rainfall patterns]
E	**Conclusion**	14. Are there any other climate change disturbances you have observed to be affecting the functioning of residential neighbourhoods in Eswatini? Elaborate if any. 15. What key climate change disturbances affecting residential neighbourhoods and their residents do you believe should be addressed urgently? Elaborate. 16. What other comments do you have concerning climate change disturbances in residential neighbourhoods? [Aiming to find out if there are other climatic changes which residential neighbourhood should adapt to, which have been left out by the researcher]

APPENDIX B: Resilience Assessment Schedule Structure

Category	**Subsystems/components**	**Variable/sub-components**	**Availability**
1. INFRASTRUCTURE	1.1. Water Management systems	Storm drains	
		Green cover	
		Community tanks	
		Sewer line	
	1.2. Water supply system	Community tanks	
		Water taps	
		Boreholes	
		Natural stream	
		Other	
	1.3. Energy source	Electricity (grid)	
		Solar panels	
		Generator	
		Firewood	
		Other	
	1.4. Road networks	*Use map*	
	1.5. Heat management system	Vegetation	
		Natural water stream	
		Wetlands	
		Other	
	1.6. Image of infrastructure		
	1.7. Location of infrastructure		
2. BUILDINGS	2.1. Building typology	Row houses	
		Kiosk	
		Market place	
		Dwelling	
		Shop	
		Workshop	
	2.2. Building materials	Adobe mud walls and metal sheet roof	
		Compressed earth block	

Category	Subsystems/components	Variable/sub-components	Availability
		walls and metal sheet roof	
		Metal sheet walls and metal sheet roof	
		Concrete blocks walls and metal sheet roof	
		Concrete blocks walls and roof tiles	
		Wooden walls and metal sheet roof	
		Other	
	2.3. Roof slope	Flat roof (exposed)	
		Flat roof with parapet walls	
		Steep roof (gable/hip)	
	2.4. Building envelope (heat adaptation)	Roof overhangs (provide shading)	
		Roof overhangs (does not provide shading)	
		Cross ventilation (opposite windows)	
		High thermal mass material (adobe blocks)	
		High thermal mass material (concrete)	
		Reflective paint	
	2.5. Building envelope (flexibility)	Expandable (allow for more space)	
		Removable/replaceable elements	
		Moveable structure	
		Accessible (alternative access doors/windows)	
		Reusable (materials)	
		Good flexibility (three and above of the above technologies)	
		Average flexibility (two of the above technologies)	
		Poor flexibility (one or no flexible technologies)	
	2.5. Building Services (energy)	Solar panels	
		Generator	
		Electricity from the grid	

Category	Subsystems/components	Variable/sub-components	Availability
		Wind turbines on site	
		Firewood	
		Other	
	2.6. Building services (water)	Water tanks	
		Public water supply connection	
		River wells	
		Boreholes	
		Other	
	2.7. Building site	Expansion space	
		Fruit trees	
		Vegetable garden	
		Other yard trees	
		Hedge	
		Water drainage channels	
		Grass cover	
		Septic tank	
		Pit toilet	
		Waste bins	
	2.8. Number of buildings in the plot		
	2.9. Image of building		
3. RESOURCES	3.1. Green networks	Vegetation	
		Park	
		Wetlands	
		Natural streams	
		Swales	
		Garden	
	3.2. Food systems	Shop	
		Market place	
		Vegetable gardens	
		Crop farming	

Category	Subsystems/components	Variable/sub-components	Availability
		Fruit trees	
	3.3. Waste disposal	Recycle centre	
		Municipality dumpster	
		Waste bins	
		Landfill	

The Epicollect5 online form used during the fieldwork (as well as the data) can be accessed through the link: https://five.epicollect.net/myprojects/msunduza-neighbourhood-surv

APPENDIX C: Resilience Assessment Results

Building #	Latitude	Longitude	Building_Typology	Building_Material	ROOF TYPE	Cooling elements	Heat Adaptation	Flexible elements	Flexibility	Energy	Water source	Food System	Site Vegetation Cover	23_Number_of_buildin
1	-26.336971	31.15747	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	Public water supp	Fruit trees	Plants	2
2	-26.337638	31.158025	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material & Cross ventilation	Average adaptation	Reusable materials	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Plants	1
3	-26.338516	31.158037	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Roof overhangs & Cross ventilation	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Vegetable garden	Plants	1
4	-26.338109	31.159854	Household (dwelling)	Concrete blocks & metal sheet roof	Steep roof (gable/hip)	Roof overhangs, Cross ventilation & Reflective paint	Good adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	No garden	No vegetation	1
5	-26.33673	31.159111	Shop (commercial)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material & Reflective paint	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Grass cover	1
6	-26.335075	31.159649	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (parapet walls)	Roof overhangs, High thermal mass material & Cros	Good adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Plants	1
7	-26.337145	31.163104	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Grass cover	2
8	-26.336497	31.162155	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Cross ventilation & Reflective paint	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Plants & grass cover	1
9	-26.335649	31.160864	Household (dwelling)	Concrete blocks walls & roof tiles	Steep roof (gable/hip)	Roof overhangs & Cross ventilation	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Hedge	1
10	-26.335261	31.160372	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Roof overhangs & Reflective paint	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees & vege	Plants & grass cover	2
11	-26.335093	31.159855	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Roof overhangs & Cross ventilation	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Plants	3
12	-26.334702	31.159176	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	Fruit trees	Hedge	1
13	-26.334576	31.158937	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (parapet walls)	Roof overhangs, Cross ventilation & Reflective paint	Good adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Plants & grass cover	3
14	-26.334551	31.158417	Household (dwelling)	Concrete blocks & metal sheet roof	Steep roof (gable/hip)	Roof overhangs	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Plants & hedge	2
15	-26.334924	31.158304	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Roof overhangs	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	No garden	Plants	1
16	-26.335055	31.158098	Kiosk (commercial)	Metal sheet walls & metal sheet roof	Flat roof (exposed)	Roof overhangs	Poor adaptation	Reusable & replacea	Average flexibility	No connection to grid	No connection to	No garden	No vegetation	1
17	-26.326152	31.155693	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Grass cover	1
18	-26.326221	31.155721	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Plants & grass cover	2
19	-26.326515	31.155799	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Roof overhangs & Reflective paint	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Plants	2
20	-26.326802	31.15582	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	Roof overhangs	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	No vegetation	1
21	-26.327073	31.155889	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	No vegetation	1
22	-26.327327	31.155959	Row houses (rental)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Roof overhangs & Cross ventilation	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	No vegetation	1
23	-26.327673	31.155171	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants	2
24	-26.32909	31.154987	Household (dwelling)	Bamboo	Flat roof (exposed)	High thermal mass material & Cross ventilation	Average adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	No garden	No vegetation	1
25	-26.328594	31.15581	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Roof overhangs, Cross ventilation & Reflective paint	Good adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees & vege	Grass cover	1
26	-26.328509	31.156078	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	Fruit trees	Plants & grass cover	1
27	-26.328506	31.156324	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	Public water supp	Fruit trees	No vegetation	1
28	-26.330157	31.157257	Row houses (rental)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Plants	1
29	-26.328217	31.157215	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	Reusable & replacea	Average flexibility	No connection to grid	No connection to	No garden	Plants	1
30	-26.328511	31.158082	Shop (commercial)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Roof overhangs & Reflective paint	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	No garden	Grass cover	1
31	-26.328263	31.157439	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants	1
32	-26.32877	31.158821	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	Fruit trees	Plants	1
33	-26.329054	31.158897	Household (dwelling)	Concrete blocks & metal sheet roof	Steep roof (gable/hip)	Roof overhangs & Cross ventilation	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	No garden	No vegetation	1
34	-26.329149	31.158764	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Roof overhangs & Reflective paint	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Plants	2
35	-26.329268	31.158594	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants	
36	-26.329376	31.158444	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	No garden	No vegetation	1
37	-26.329672	31.158271	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	Fruit trees	Plants	1
38	-26.330086	31.157885	Row houses (rental)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	Fruit trees	Plants	3
39	-26.330219	31.157748	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	No garden	No vegetation	1
40	-26.330614	31.157813	Household (dwelling)	Concrete blocks walls & roof tiles	Steep roof (gable/hip)	Roof overhangs & Cross ventilation	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Plants & grass cover	1
41	-26.331359	31.158034	Row houses (rental)	Adobe mud walls & metal sheet roof,	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	No garden	Plants	1
42	-26.33135	31.15782	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants & grass cover	1
43	-26.331435	31.157699	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	Fruit trees	Plants	1
44	-26.331558	31.157241	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	No garden	No vegetation	1
45	-26.33106	31.156894	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Plants	1
46	-26.330492	31.1569	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants	2
47	-26.330489	31.156913		Concrete blocks & metal sheet roof	Flat roof (exposed)	Roof overhangs & Reflective paint	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	No vegetation	2
48	-26.3303	31.15712	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	No vegetation	1
49	-26.329995	31.15672	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants	1
50	-26.330459	31.156589	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	No garden	No vegetation	3
51	-26.330261	31.156443	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material & Cross ventilation	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	No vegetation	1
52	-26.330828	31.156805	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Cross ventilation	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	No garden	No vegetation	1
53	-26.331324	31.156818	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	Fruit trees	No vegetation	2
54	-26.331425	31.156761	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Reflective paint	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	No vegetation	2
55	-26.331753	31.156576	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	Fruit trees	No vegetation	2
56	-26.331347	31.156478	Household (dwelling)	Metal sheet walls & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	No garden	No vegetation	
57	-26.33119	31.156145	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	No garden	No vegetation	
58	-26.33125	31.156004	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	No garden	No vegetation	1
59	-26.330341	31.15486	Kiosk (commercial)	Wooden walls & metal sheet roof	Steep roof (gable/hip)	Cross ventilation	Poor adaptation	Reusable & replacea	Average flexibility	No connection to grid	No connection to	No garden	No vegetation	1
60	-26.320204	31.151354	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	No vegetation	1
61	-26.319881	31.150949	Row houses (rental)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Plants	1
62	-26.320108	31.15096	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	No garden	No vegetation	1
63	-26.320486	31.151067	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	No vegetation	2
64	-26.320677	31.151088	Row houses (rental)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants	2
65	-26.321015	31.151322	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Plants	1
66	-26.321236	31.151538	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	No garden	No vegetation	1
67	-26.321256	31.152493	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	No garden	No vegetation	1
68	-26.321235	31.153073	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	No garden	No vegetation	2
69	-26.321328	31.153712	Row houses (rental)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material & Cross ventilation	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	No garden	No vegetation	2
70	-26.321328	31.154056	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Roof overhang, Cross ventilation & Reflective paint	Good adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Grass cover & hedge	1
71	-26.321673	31.154133	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	Fruit trees	Plants	1
72	-26.321118	31.154897	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants	2
73	-26.32101	31.154604	Household (dwelling)	Metal sheet walls & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Plants	1
74	-26.320873	31.154674	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants	1
75	-26.32129	31.154402	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	Cross ventilation	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants	2

76	-26.321542	31.154236	Row houses [rental]	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Water tank	Fruit trees & vege	Plants	2
77	-26.322077	31.154311	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants	1
78	-26.322195	31.15454	Row houses [rental]	Metal sheet walls & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	Fruit trees	No vegetation	
79	-26.322381	31.154557	Household (dwelling)	Concrete blocks & metal sheet roof	Steep roof (gable/hip)	Roof overhangs	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Plants	1
80	-26.322567	31.154438	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	No garden	Plants & grass cover	1
81	-26.322776	31.154364	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Roof overhangs & Reflective paint	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	No garden	Hedge	1
82	-26.322926	31.154267	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Vegetable garden	Plants	2
83	-26.322823	31.153797	Row houses [rental]	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	No garden	No vegetation	2
84	-26.32225	31.153302	Household (dwelling)	Concrete blocks & metal sheet roof	Steep roof (gable/hip)	Roof overhangs & Reflective paint	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees & vege	No vegetation	1
85	-26.322548	31.153315	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	Fruit trees	Plants & hedge	2
86	-26.331981	31.157853	Shop [commercial]	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	No garden	Plants	
87	-26.332291	31.158444	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	Fruit trees	Plants	
88	-26.332628	31.15873	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Roof overhangs & Cross ventilation	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Plants	1
89	-26.332778	31.159261	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	Roof overhangs & Reflective paint	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	No garden	Hedge	2
90	-26.333157	31.160104	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	Cross ventilation	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	No garden	No vegetation	
91	-26.333115	31.161066	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants	2
92	-26.333595	31.161823	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	Fruit trees	Plants	2
93	-26.333839	31.162162	Kiosk [commercial]	Wooden walls & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	No garden	No vegetation	1
94	-26.334059	31.162787	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants	2
95	-26.334189	31.162915	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants	2
96	-26.334432	31.163098	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Roof overhangs	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	No vegetation	3
97	-26.334581	31.16329	Kiosk [commercial]	Metal sheet walls & metal sheet roof	Flat roof (exposed)	Roof overhangs	Poor adaptation	Reusable & replacea	Average flexibility	No connection to grid	No connection to	No garden	No vegetation	1
98	-26.33505	31.163816	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	Fruit trees	Plants	2
99	-26.334912	31.164348	Household (dwelling)	Concrete blocks walls & roof tiles	Steep roof (gable/hip)	Roof overhangs	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	No garden	Plants	2
100	-26.334369	31.164126	Row houses [rental]	Concrete blocks & metal sheet roof	Flat roof (exposed)	Roof overhangs	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	No garden	Plants	1
101	-26.3335	31.163954	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material & Cross ventilation	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants	1
102	-26.333019	31.164683	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants	2
103	-26.331681	31.153677	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Roof overhangs	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Plants, grass cover & he	1
104	-26.332467	31.164189	Household (dwelling)	Concrete blocks walls & roof tiles	Steep roof (gable/hip)	Cross ventilation & Reflective paint	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants & hedge	1
105	-26.331898	31.163712	Household (dwelling)	Concrete blocks walls & roof tiles	Steep roof (gable/hip)	Roof overhangs	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees & vege	Plants	1
106	-26.331411	31.162964	Household (dwelling)	Concrete blocks & metal sheet roof	Steep roof (gable/hip)	Roof overhangs	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants	1
107	-26.331221	31.162128	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	Fruit trees	Plants	2
108	-26.330937	31.161313	Row houses [rental]	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material & Cross ventilation	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants, grass cover & he	1
109	-26.330877	31.161014	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants & grass cover	1
110	-26.330808	31.160622		Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	Fruit trees	Plants	2
111	-26.331133	31.160197	Kiosk [commercial]	Wooden walls & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	Reusable & replacea	Average flexibility	No connection to grid	No connection to	No garden	No vegetation	1
112	-26.331305	31.159993	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	Fruit trees	Plants	2
113	-26.331681	31.153677	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Cross ventilation	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants	1
114	-26.331951	31.159617	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	Fruit trees	Plants & hedge	4
115	-26.332377	31.159536		Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	Fruit trees	Plants	1
116	-26.3325	31.159428	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	No garden	No vegetation	4
117	-26.332729	31.158962	Row houses [rental]	Concrete blocks & metal sheet roof	Flat roof (exposed)	Cross ventilation	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	No garden	No vegetation	2
118	-26.332598	31.158706	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	Roof overhangs & Cross ventilation	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Grass cover	1
119	-26.335716	31.156183	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	Fruit trees	Plants	2
120	-26.331849	31.155944	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	Fruit trees	No vegetation	1
121	-26.331151	31.155182	Workshop [commercial	Metal sheet walls & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	Reusable, replaceabl	Average flexibility	No connection to grid	No connection to	No garden	Plants	2
122	-26.330044	31.15492	Workshop [commercial	Metal sheet walls & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	Reusable & replacea	Average flexibility	No connection to grid	No connection to	No garden	No vegetation	1
123	-26.335171	31.158316	Shop [commercial]	Concrete blocks & metal sheet roof	Flat roof (parapet walls)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	No garden	No vegetation	
124	-26.336319	31.158995	Kiosk [commercial]	Other (state on comment section)	Flat roof (exposed)	High thermal mass material	Poor adaptation	Reusable & replacea	Average flexibility	No connection to grid	No connection to	No garden	No vegetation	2
125	-26.336912	31.158593	Kiosk [commercial]	Wooden walls & metal sheet roof	Flat roof (exposed)	Roof overhangs, High thermal mass material & Cros	Good adaptation	Reusable & replacea	Average flexibility	No connection to grid	No connection to	No garden	No vegetation	1
126	-26.336807	31.158338	Shop [commercial]	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	No garden	No vegetation	3
127	-26.33678	31.157946	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (parapet walls)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	No garden	No vegetation	1
128	-26.33706	31.157637	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	Fruit trees	No vegetation	2
129	-26.33657	31.159222	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants	4
130	-26.335864	31.158702	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants	2
131	-26.336047	31.156183	Kiosk [commercial]	Bamboo	Flat roof (exposed)	High thermal mass material & Cross ventilation	Average adaptation	Reusable & replacea	Average flexibility	No connection to grid	No connection to	No garden	No vegetation	2
132	-26.335458	31.158389	Household (dwelling)	Concrete blocks & metal sheet roof	Steep roof (gable/hip)	Roof overhangs & Cross ventilation	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	No vegetation	2
133	-26.335488	31.158444	Row houses [rental]	Concrete blocks & metal sheet roof	Flat roof (exposed)	Cross ventilation	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants	3
134	-26.335057	31.158176	Kiosk [commercial]	Metal sheet walls & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	Reusable & replacea	Average flexibility	No connection to grid	No connection to	No garden	No vegetation	1
135	-26.322496	31.152356	Kiosk [commercial]	Metal sheet walls & metal sheet roof	Flat roof (exposed)	Roof overhangs & Cross ventilation	Average adaptation	Removeable elemen	Average flexibility	No connection to grid	No connection to	No garden	No vegetation	1
136	-26.322716	31.152753		Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees & vege	No vegetation	1
137	-26.322892	31.153172	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Roof overhangs	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Plants	2
138	-26.322114	31.15257	Kiosk [commercial]	Wooden walls & metal sheet roof	Flat roof (exposed)	Roof overhangs & Cross ventilation	Average adaptation	Reusable & replacea	Average flexibility	No connection to grid	No connection to	Fruit trees	Plants	1
139	-26.322098	31.152969	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Roof overhangs & Cross ventilation	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees & vege	Plants	1
140	-26.321761	31.152818	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	No vegetation	1
141	-26.321755	31.152756	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	Roof overhangs & High thermal mass material	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	No vegetation	1
142	-26.321526	31.152255	Row houses [rental]	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants	2
143	-26.321389	31.152116	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	No vegetation	1
144	-26.321293	31.151677	Row houses [rental]	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Plants & grass cover	1
145	-26.322117	31.151805	Shop [commercial]	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	No garden	Grass cover	1
146	-26.322285	31.152051	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	Fruit trees	No vegetation	1
147	-26.331817	31.155616	Kiosk [commercial]	Other (state on comment section)	Steep roof (gable/hip)	High thermal mass material & Cross ventilation	Average adaptation	Reusable & replacea	Average flexibility	No connection to grid	No connection to	No garden	No vegetation	1
148	-26.332006	31.156257	Row houses [rental]	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	Fruit trees	No vegetation	1
149	-26.331991	31.156648	Shop [commercial]	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	No vegetation	1
150	-26.33199	31.158018	Shop [commercial]	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	No garden	No vegetation	1
151	-26.331707	31.158436	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Plants	1

152	-26.331495	31.158709	Kiosk [commercial]	Wooden walls & metal sheet roof	Steep roof (gable/hip)	High thermal mass material	Average adaptation	Reusable & replacea	Average flexibility	No connection to grid	No connection to	No garden	No vegetation	
153	-26.331332	31.159821	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Roof overhangs, Cross ventilation & Reflective paint	Good adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants & hedge	3
154	-26.331062	31.159563	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	No vegetation	1
155	-26.330894	31.159087	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants	1
156	-26.331141	31.15891	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	Cross ventilation	Poor adaptation	Reusable materials	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants	2
157	-26.331188	31.158932	Row houses [rental]	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Plants	1
158	-26.330978	31.15854	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants	2
159	-26.330706	31.158112	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	Roof overhangs, High thermal mass material & Cros	Good adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants	1
160	-26.330611	31.157725	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Reflective paint	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	No vegetation	2
161	-26.330994	31.157363	Row houses [rental]	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	No vegetation	1
162	-26.331454	31.157261	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	No garden	No vegetation	1
163	-26.331816	31.157008	Shop [commercial]	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	No garden	No vegetation	1
164	-26.332117	31.157317	Workshop [commercial	Metal sheet walls & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	Reusable elements &	Average flexibility	Electricity from grid	No connection to	No garden	No vegetation	1
165	-26.332497	31.157486	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	No vegetation	3
166	-26.33273	31.15754	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	Reusable materials	Poor flexibility	No connection to grid	No connection to	Fruit trees	No vegetation	1
167	-26.332989	31.157271	Kiosk [commercial]	Metal sheet walls & metal sheet roof	Flat roof (exposed)	Roof overhangs	Poor adaptation	Reusable materials	Average flexibility	No connection to grid	No connection to	Fruit trees	No vegetation	1
168	-26.333133	31.157197	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	Fruit trees	No vegetation	2
169	-26.33347	31.157275	Household (dwelling)	Concrete blocks & metal sheet roof	Steep roof (gable/hip)	Roof overhangs & Cross ventilation	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Grass cover	1
170	-26.333257	31.156601	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	No vegetation	2
171	-26.332827	31.155946	Row houses [rental]	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Grass cover	2
172	-26.333424	31.15594	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	Reusable materials	Poor flexibility	No connection to grid	No connection to	Fruit trees	No vegetation	2
173	-26.332943	31.15561	Household (dwelling)	Concrete blocks & metal sheet roof	Steep roof (gable/hip)	Roof overhangs, Cross ventilation & Reflective paint	Good adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	No vegetation	3
174	-26.332496	31.155039	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees & vege	Grass cover	3
175	-26.327703	31.155485	Kiosk [commercial]	Wooden walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	Reusable & replacea	Average flexibility	No connection to grid	No connection to	No garden	No vegetation	3
176	-26.327731	31.155478	Household (dwelling)	Wooden walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	Reusable & replacea	Average flexibility	Electricity from grid	No connection to	Fruit trees	No vegetation	2
177	-26.327289	31.155918	Row houses [rental]	Concrete blocks & metal sheet roof	Flat roof (exposed)	Cross ventilation	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	No vegetation	1
178	-26.32732	31.156941	Kiosk [commercial]	Metal sheet walls & metal sheet roof	Flat roof (exposed)	Roof overhangs	Poor adaptation	Reusable & replacea	Average flexibility	No connection to grid	No connection to	Fruit trees	No vegetation	1
179	-26.327485	31.157342	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	No garden	No vegetation	1
180	-26.327838	31.157222	Row houses [rental]	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	No garden	No vegetation	2
181	-26.328121	31.158299	Kiosk [commercial]	Metal sheet walls & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	Reusable & replacea	Average flexibility	No connection to grid	No connection to	No garden	No vegetation	1
182	-26.328353	31.158078	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	Roof overhangs & High thermal mass material	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Grass cover	1
183	-26.328821	31.158391	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Roof overhang	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	No garden	No vegetation	1
184	-26.328588	31.158296	Row houses [rental]	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	No garden	Plants	3
185	-26.328674	31.1579	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Roof overhangs & Cross ventilation	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	No vegetation	1
186	-26.328682	31.157447	Market place	Metal sheet walls & metal sheet roof	Flat roof (exposed)	Roof overhangs	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	No garden	Grass cover	1
187	-26.329075	31.157059	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	No garden	Grass cover	2
188	-26.33005	31.157026	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	No vegetation	2
189	-26.329438	31.156306	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	No garden	Grass cover	1
190	-26.329356	31.15629	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Plants	1
191	-26.329106	31.156318	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	No vegetation	1
192	-26.329045	31.155852	Kiosk [commercial]	Wooden walls & metal sheet roof	Steep roof (gable/hip)	Roof overhangs, High thermal mass material & Cros	Good adaptation	Reusable & replacea	Good flexibility	No connection to grid	No connection to	No garden	Grass cover	1
193	-26.329234	31.155956	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Cross ventilation	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Grass cover	2
194	-26.328762	31.155815	Kiosk [commercial]	Metal sheet walls & metal sheet roof	Flat roof (exposed)	Cross ventilation	Average adaptation	Reusable & replacea	Average flexibility	No connection to grid	No connection to	No garden	Grass cover	1
195	-26.328671	31.155491	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Roof overhangs	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Grass cover	1
196	-26.329336	31.154094	Market place	Concrete blocks & metal sheet roof	Steep roof (gable/hip)	Roof overhangs & Cross ventilation	Average adaptation	Removeable elemen	Average flexibility	Electricity from grid	Public water supp	No garden	No vegetation	1
197	-26.327653	31.155016	Shop [commercial]	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	No garden	No vegetation	1
198	-26.325061	31.154593	Row houses [rental]	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees & vege	Plants	3
199	-26.325648	31.154636	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	No garden	No vegetation	2
200	-26.325763	31.1544	Workshop [commercial	Metal sheet walls & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	Reusable & replacea	Good flexibility	Electricity from grid	Public water supp	Fruit trees & vege	Plants	2
201	-26.325706	31.154163	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees & vege	Plants	2
202	-26.325859	31.154689	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	No vegetation	2
203	-26.32648	31.155145	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Cross ventilation	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	No garden	No vegetation	2
204	-26.326985	31.154861	Household (dwelling)	Metal sheet walls & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	Reusable & replacea	Average flexibility	No connection to grid	No connection to	Fruit trees	Plants	2
205	-26.327316	31.155183	Household (dwelling)	Compressed earth block walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	No vegetation	2
206	-26.327812	31.155279	Household (dwelling)	Concrete blocks walls & roof tiles	Steep roof (gable/hip)	Roof overhangs, Cross ventilation & Reflective paint	Good adaptation	Accessible structure	Poor flexibility	Electricity from grid	Public water supp	No garden	No vegetation	1
207	-26.328855	31.155295	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	Public water supp	Fruit trees	Grass cover	2
208	-26.32923	31.15507	Shop [commercial]	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	No garden	Grass cover	2
209	-26.327129	31.153933	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material & Cross ventilation	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	No garden	Plants & grass cover	2
210	-26.326975	31.15353	Shop [commercial]	Concrete blocks & metal sheet roof	Flat roof (exposed)	High thermal mass material & Reflective paint	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	No garden	No vegetation	1
211	-26.326028	31.153632	Workshop [commercial	Metal sheet walls & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	Reusable & replacea	Average flexibility	No connection to grid	No connection to	No garden	No vegetation	1
212	-26.325773	31.153783	Shop [commercial]	Concrete blocks & metal sheet roof	Flat roof (parapet walls)	No heat control	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	No garden	No vegetation	1
213	-26.326018	31.154196	Kiosk [commercial]	Metal sheet walls & metal sheet roof	Flat roof (exposed)	Roof overhangs	Poor adaptation	No flexible elements	Average flexibility	No connection to grid	No connection to	No garden	No vegetation	
214	-26.325922	31.154201	Kiosk [commercial]	Wooden walls & metal sheet roof	Flat roof (exposed)	Roof overhangs, High thermal mass material & Cros	Good adaptation	Reusable & replacea	Good flexibility	No connection to grid	No connection to	No garden	No vegetation	1
215	-26.326422	31.154158	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Roof overhangs & Cross ventilation	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees & vege	Plants	1
216	-26.326576	31.154512	Household (dwelling)	Wooden walls & metal sheet roof	Flat roof (exposed)	Roof overhangs, Cross ventilation & Reflective paint	Good adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees & vege	Grass cover	1
217	-26.326864	31.154507	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Reflective paint	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	No garden	No vegetation	1
218	-26.327557	31.154308	Household (dwelling)	Concrete blocks & metal sheet roof	Steep roof (gable/hip)	Roof overhangs & Cross ventilation	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	No garden	No vegetation	1
219	-26.327898	31.154695	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	Reusable & replacea	Average flexibility	Electricity from grid	Public water supp	Fruit trees	Grass cover	2
220	-26.32009	31.151449	Row houses [rental]	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	No connection to grid	No connection to	Fruit trees	No vegetation	1
221	-26.320599	31.151465	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Roof overhangs & Cross ventilation	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	No vegetation	1
222	-26.321042	31.151996	Row houses [rental]	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	Fruit trees	Hedge	1
223	-26.321364	31.151465	Household (dwelling)	Concrete blocks & metal sheet roof	Steep roof (gable/hip)	Roof overhangs & Cross ventilation	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Hedge	
224	-26.321537	31.151138	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Cross ventilation	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	No connection to	No garden	No vegetation	
225	-26.32397	31.153842	Kiosk [commercial]	Wooden walls & metal sheet roof	Flat roof (exposed)	Roof overhangs, High thermal mass material & Cros	Good adaptation	Reusable & replacea	Good flexibility	No connection to grid	No connection to	No garden	No vegetation	1
226	-26.32368	31.154755	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Roof overhangs	Poor adaptation	Expandable structur	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Grass cover	
227	-26.323566	31.154528	Row houses [rental]	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	Reusable materials	Poor flexibility	No connection to grid	No connection to	Fruit trees	No vegetation	
228	-26.323648	31.154367	Household (dwelling)	Concrete blocks & metal sheet roof	Flat roof (exposed)	Roof overhangs & Cross ventilation	Average adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Hedge	1
229	-26.323753	31.154125	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	High thermal mass material	Poor adaptation	No flexible elements	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Grass cover	2
230	-26.323697	31.154088	Household (dwelling)	Adobe mud walls & metal sheet roof	Flat roof (exposed)	No heat control	Poor adaptation	Reusable materials	Poor flexibility	Electricity from grid	Public water supp	Fruit trees	Grass cover	2

APPENDIX D: Evaluation form of design strategies of informal settlements

Area of specialisation: *Architect, Environmentalist, Academic, Disaster Management, Urban Planner*

Role in your organisation: Consultant, Disaster Management, Environmental management, lecturing **Date**: *28 April 2023 to 4 May 2023*

Category	Strategy	Constructability	Affordability	Acceptability	Regulatory	Effectiveness
1. Buildings	**1.1. Extreme heat management**					
	1.1.1. Diversity of solar/radiation control					
	● *Windows oriented to the north-south*					
	● *Long roof overhangs providing shading to windows and walls*					
	● *Reflective paint for walls and roofing (cool roofs)*					
	1.1.2. Redundancy of passive ventilation technologies					
	● *One-room width buildings with opposite windows*					
	● *Ventilation chimneys/ shafts*					
	● *Perforation on walls*					
	● *Perforation on doors and windows (allow air access even when closed)*					
	1.1.3. Diversity of approaches to control heat gain					
	● *Install ceilings in buildings roofed with metal sheets*					
	● *Local and high thermal mass materials e.g., fired clay bricks, bamboo, wood shingles, adobe mud bricks, etc*					
	● *green roofs*					
	1.1.4. Flexible building envelope (transformation)					

Category	Strategy	Constructability	Affordability	Acceptability	Regulatory	Effectiveness
	• *operable windows (not fixed)*					
	• *mobile houses*					
	• *adjustable wall thicknesses*					
	• *moveable interior walls*					
	1.1.5. Building site cooling					
	• *water ponds/fountains (evaporative cooling)*					
	• *yard trees*					
	1.2. Managing flooding					
	1.2.1. Redundancy of water collection technologies					
	• *gutter system connecting to water tanks*					
	• *rainwater gardens*					
	1.2.2. Diversity of waterproofing technologies					
	• *water resistant building materials e.g. waterproof plaster*					
	• *blue-green roofs*					
	• *steep roof slope (as per manufacturers' requirements)*					
	1.2.3. Flexible building					
	• *removable interior walls*					
	• *removable fittings*					
	• *building on pilotis to allow storm water to flow underneath the building*					
	1.3. Managing storms					
	1.3.2. Diversity of wind management systems					

Category	Strategy	Constructability	Affordability	Acceptability	Regulatory	Effectiveness
	• *plant, transplant or retain trees around buildings*					
	• *steep roof cognisant of prevailing winds*					
	• *parapet walls*					
	• *short roof overhangs on building sides facing prevailing winds*					
	• *secure roof structure to beams*					
	1.3.3. Redundancy of energy supply					
	• *use of solar panels*					
	• *power generators*					
	• *use of biodigester to generate energy*					
	• *microgrid*					
2. Infrastructure	**2.1. Managing extreme heat**					
	2.1.1. Diversity of cooling technologies					
	• *water features/ponds (evaporative cooling)*					
	• *incorporate man-made and natural wetlands (evaporative cooling)*					
	• *open spaces/out-door sitting areas*					
	• *diversity of tree species*					
	• *street tree canopy*					
	• *replace cut trees*					
	2.2. Managing flooding					
	2.2.1. Diversity of water management technologies					
	• *porous pavers*					

Category	Strategy	Constructability	Affordability	Acceptability	Regulatory	Effectiveness
	• *green soil cover*					
	• *rainwater gardens*					
	• *natural water attenuation basin/park/pond*					
	• *flood walls*					
	2.2.2. Regenerate waterways					
	• *clean waterways such as rivers and swamps*					
	• *maintenance of flood pathways*					
	• *widen storm drains to increase capacity/sustain them*					
	• *one-way valves in sewer systems*					
	2.2.3. Redundancy (alternative) water supply					
	• *water reservoirs (community water tanks)*					
	• *community boreholes*					
	2.3. Managing storms					
	2.3.1. Redundancy/alternative energy systems					
	• *community power generators*					
	• *community solar panels and photovoltaic panels*					
	• *community wind turbines*					
	• *electricity from the grid (EEC)*					
	2.3.2. Redundancy of communication systems					
	• *fixed telephone lines*					
	• *mobile phone network towers*					

Category	Strategy	Constructability	Affordability	Acceptability	Regulatory	Effectiveness
3. Resources	**3.1. Managing extreme heat, flooding, and storms**					
	3.1.1. Encourage biodiversity					
	● *plant different tree species along streets, parks, within homesteads, etc*					
	3.1.2. Functional diversity of food systems					
	● agricultural producing					
	● kiosks along streets					
	● centralized vegetable marketplaces					
	● grocery shops along streets					
	3.1.3. Functional diversity of waste disposal systems					
	● municipality dumpsters					
	● recycle centre					
	● use horticulture waste as organic fertilizer					

5- very high, 4- high, 3- neutral, 2- low and 1- very low

Linkert scale: 5- Very high, 4- High, 3- Neutral, 2- Low and 1- Very low.

APPENDIX E: Confirmation of Ethics approval to undertake the research

Faculty of Engineering, Built Environment and Information Technology

Fakulteit Ingenieurswese, Bou-omgewing en Inligtingtegnologie / Lefapha la Boetšenere, Tikologo ya Kago le Theknolotši ya Tshedimošo

Reference number: EBIT/9/2021

Mr MG Ndlangamandla
Department: Architecture
University of Pretoria
Pretoria
0083

Dear Mr MG Ndlangamandla

FACULTY COMMITTEE FOR RESEARCH ETHICS AND INTEGRITY

Your recent application to the EBIT Research Ethics Committee refers.

Conditional approval is granted.

This means that the research project entitled "Design and Development Strategies of Affordable Housing Settlements for Climate Change Resilience in Eswatini" is approved under the strict conditions indicated below. If these conditions are not met, approval is withdrawn automatically.

Conditions for approval
Informed consent form: Item iv(c) - Respondents should be informed that they may also choose for interviews NOT to be recorded, and that they may receive a copy of the recording should the interview be recorded and should they choose so.

Sampling: Because respondents are likely to be sampled via professional referrals (snowball sampling) and contacted via their organisations (e.g., work email addresses), and because they will be answering questions that are either directly or indirectly related to their professional duties, letters of permission from employers should rather be obtained. These can be submitted in due course to the EBIT REC.

This approval does not imply that the researcher, student or lecturer is relieved of any accountability in terms of the Code of Ethics for Scholarly Activities of the University of Pretoria, or the Policy and Procedures for Responsible Research of the University of Pretoria. These documents are available on the website of the EBIT Ethics Committee.

If action is taken beyond the approved application, approval is withdrawn automatically.

According to the regulations, any relevant problem arising from the study or research methodology as well as any amendments or changes, must be brought to the attention of the EBIT Research Ethics Office.

The Committee must be notified on completion of the project.

The Committee wishes you every success with the research project.

Prof K.-Y. Chan
Chair: Faculty Committee for Research Ethics and Integrity
FACULTY OF ENGINEERING, BUILT ENVIRONMENT AND INFORMATION TECHNOLOGY

APPENDIX F: Examination Comments

Revisions made as per comments from Examiner's Reports.			
Date: January 2024			
Examiner 1: Dr JM Hugo			
Comment		**Section (Chapter, Section, Page no)**	**Action**
	Introduction:		
1	Currently the research objective, which I would argue is rather the research aim, also mentions improving the wellbeing of residents, which is not mentioned in the research question. Consider whether the objective can be revised to suite the research question.	Chapter 1, Section 1.5, Page 6	Addressed. The objective has been revised by removing the aspect of 'improving the wellbeing of residents.'
2	Sub-objective three, which I would rather call objective, needs better definition to be aligned with the sub-question 3. I suggest careful consideration if wellbeing was addressed in the study (and should be included).	Chapter 1, Section 1.5.3, Page 6	Addressed. Sub-objective three has been revised to better align with sub-question 3. 'Wellbeing' was not addressed in the study, and the objective has been revised as per comment 1 above.
3	In terms of the study limitations, justify using local precedents and then also including precedent studies from other regions which address other climate change risks?	Chapter 1, Section 1.6.1, Page 6	Addressed.
4	Introduction paragraph: check your quantities (or how it is reported) if 77% of the global urban population lives in less developed urban areas, how can the population only reach 2 billion by 2050 (that is less than 50% of the current 4.4 billion). Consider how this is communicated.	Chapter 1, Section 1.1, Page 1	Addressed. One sentence of the paragraph has been rephrased.
5	A direct quote from Roberts (2008) is included in the introduction but the page reference is not provided.	Chapter 1, Section 1.2,	Addressed.

		Page 3	The page number has been provided as Roberts (2008:4552).
6	Consider whether papers written in 2011 can be considered recent as stated in introduction (page 4).	Chapter 1, Section 1.2, Page 4	Addressed. The word 'recent' has be replaced with 'some'.
	Literature Review:		
7	Urban and sustainability. Unfortunately at the end of the section, the conclusion takes a rather simplistic stance stating that it should be studied together. I think you miss an opportunity to highlight their relationship and interrelatedness.	Chapter 2, Section 2.5.1, Page 45	Noted. A minor adjustment has been made by adding a paragraph to expand the point that in the study of sustainability, the two terms are tied together.
8	The discussion on the characteristics of resilience is valuable, yet in 2.8 the PhD candidate mentions 6 main characteristics, but then chooses to only discuss 4 of the 6. Why?	Chapter 2, Section 2.5.3, Page 47	Clarification: The six characteristics are quoted from Ribeiro and Goncalves (2019). It is stated on page 48 that four of the characteristics are the most vital and Dastjerdi et al. (2021) was referenced.
9	The discussion on "Determining the resilience of a system "provides limited discussion on the nature of or how to determine the resilience (even though several characteristics were communicated). This is a missed opportunity.	Chapter 2, Section 2.5.4, Page 53	Clarification: The discussion is in Chapter 6.
10	The resilience attributes discussed in the conclusion of the literature review, only states a small selection of the attributes discussed in the chapter, these are incomplete and limits the reader's understanding of critical attributes to consider - connectivity, robustness and adaptation is not mentioned. Why?	Chapter 2, Section 2.7, Page 71	Clarification: The most common attributes in literature have been considered: redundancy, modularity, diversity and connectivity. However, connectivity has been included.
11	While the conclusion unpacks the logical argument for the study and its focus, the main themes/definitions that are typically employed in Resilience thinking and a scope of the tools used in such studies. The	Chapter 2, Section 2.7, Page 71	Addressed. The gap has been highlighted.

	conclusion misses the opportunity to highlight a research need or gap which supports the study that is undertaken. This can be valuable to guide the reader but also future students considering the literature review.		
12	In the background section the PhD candidate notes the "use of energy in construction", this is a misinterpretation of the term construction. I suggest that one rather uses the term built environment.	Chapter 2, Section 2.2, Page 14	Addressed as suggested. The term 'construction' has been changed to 'built environment'.
13	On page 17 the PhD candidate reports on a number of effects caused by climate change. Consider the word choice: "...overheating effects, flooding effects, storm effects, and effects caused by fire…" What are those effects caused by fire?	Chapter 2, Section 2.2.1, Page 17	Addressed. The effects are highlighted in Table 2.2. A reference to the table has been made.
14	Statement on page 42: "Urban areas globally are facing rapid population growth since the industrial revolution when workers started shifting to manufacturing companies in these areas" this statement is unclear. Do you mean there was a shift in the labour market that result in change in land-use patterns? This can be more explicitly stated.	Chapter 2, Section 2.5, Page 42	Addressed. The sentence was rephrased.
15	Unpacking the evolution of resilience is valuable, yet the last stage (current stage) as argued by Masnavi et al. (2019), requires more explicit clarification: "The last and current stage, explores the principles of the concept of resilient cities, emphasizing the coexistence of urban systems with environmental hazards as well as a holistic approach to resilience in urban systems (Masnavi et al., 2019)." What is meant by this statement, resilience as discussed in your literature review comes from a tradition of understanding disruptions and the recovery of systems. This statement does not clarify the current thinking in the discourse as you are communicating.	Chapter 2, Section 2.5, Page 42	Clarification: The evolution of resilience thinking in this section is quoted from Masnavi et al. (2019). The understanding is that resilience is now considering the coexistence of urban systems with environmental hazards, which was not the case in the preceding three levels.
16	On Page 66 – Reference the sustainable development goals (whose goals) are you referring to?	Chapter 2, Section 2.6.5, Page 66	Addressed. The reference has been added.
	Research methods:		

17	The precedent choices were discussed but the reasoning for the choices were not discussed. Also consider what you mean with local and international studies - most of the precedents were international if you are located in Eswatini.	Chapter 3, Section 3.3.3, Page 84	Clarification: A selection criterion was presented in the same section. The meaning of local and international studies was clarified where it appears in Chapter 3 and Chapter 8.
18	Interviews: Generally clear. A few missing aspects were the duration of the interviews, how and where it was undertaken and general topics that were discussed.	Chapter 3, Section 3.3.1, Page 77	Addressed. The duration and place of interviews have been added. Reference was initially made to Appendix A for the general topics which were discussed. In Chapter 5 the topics are discussed in depth.
19	Observational analysis: "A structured observation checklist data collection tool was used." - Which tool was this?	Chapter 3, Section 3.3.2, Page 79	Clarification: The tool was developed by the research as stated in the same section. The tool is presented in Appendix B as referenced.
20	Did you follow an inductive or deductive approach to establish the observational analysis tool? How did you establish the criteria or analysis?	Chapter 3, Section 3.3.2.2, Page 80	Addressed. An abductive approach was used, building from the work of Peres (2016) and results from sub-question 1. See Figure 3.2. This has been further clarified.
21	Page 80: Why did you choose to use "simple, systematic, stratified, and cluster sampling". This needs clarification why would you choose to follow all four methods of sampling. Which sampling method/s did you follow?	Chapter 3, Section 3.3.2.2, Page 81	Clarification: Refer to the two sentences: "This study used probability sampling which consists of simple, systematic, stratified, and cluster sampling. Systematic random sampling was chosen for this study. It involves the researcher choosing the sample at regular intervals from the targeted sample."
22	Precedent Analysis: The selection of precedent studies requires careful consideration and justification. Why did the PhD candidate choose to not consider case studies on flooding and storms located in Africa, and only considered case studies on flooding and storms located in Africa,	Chapter 3, Section 3.3.3.1, Page 84	Clarification: The search of precedents based on the presented criteria did not give results of precedents that addressed flooding

	and only considered the first 10 case studies located outside Africa.		and storms in Africa, hence the identification of additional relevant international (outside Africa) precedents. The first 10 studies were selected since the study reached saturation. Consider the following paragraph in the same section: "The precedents selected for study seemed to mainly address overheating impacts, possibly because of their location (East Africa) where overheating is the main concern. This study was therefore extended to complement the technologies reviewed in Clegg and Sandeman (2019), and for purposes of triangulation. Ten more precedents were purposely selected through Google search and Google Scholar using the search terms 'climate change responsive designs'."
	Research findings:		
	Sub question 2		
23	On page 133 it is noted that the lack of services provision lead to "...crime, prostitution…" This correlation is unclear. Consider how this statement can be adjusted.	Chapter 6, Section 6.2.4, Page 133	Clarification: This was quoted from MHUD (2007) - *A Brief History of Urban Development and Upgrading in Swaziland*
24	Why did the PhD candidate choose to only consider redundancy, modularity and diversity as resilience attributes and not also connectivity as discussed and structured in the literature review?	Chapter 6, Section 6.4	Clarification: 'Connectivity' is discussed under movement systems in Section 6.4.1.6
25	Page 142 - Consider this statement: The storm drain system does not connect or dispose to the sewer system at Msunduza as that is not permitted by the Eswatini Water Service Corporation which manages the sewer systems in Eswatini. *The sewer system therefore only manages wastewater; however, it is not the case at Msunduza and that results in the overwhelmed storm drain systems.* The logic is unclear here - revised the sentence or the logic of the statement.	Chapter 6, Section 6.4.1.1, Page 142	Addressed. The sentence structure has been revised.

26	Energy supply redundancy: how readily available are biofuels? How effective is it and what are the drawbacks and concerns?	Chapter 6, Section 6.4.1.4, Page 149	Clarification: The study only identified/ listed the following sources of energy: public electricity supply, solar panels, generators, and firewood, based on the findings from the precedent studies.
27	Table 6.5 Building types do not make up 100% of the settlement. Check the quantities or clarify the gap in quantities.	Chapter 6, Section 6.4.2.1, Page 151	Addressed. The percentage of workshop buildings were adjusted.
28	It is important to clarify the difference between building function (or types) and building typology. At the moment it is mixed. Row house is a building typology, while dwellings are building types/functions that are the same as row houses. Consider the terminology that is used.	Chapter 6, Section 6.4.2.1, Page 152	Addressed. The term ‘dwelling building’ has been changed to ‘standalone house’.
29	When communicating descriptive statistics it is always good to also provide a table that discusses the criteria considered and the number of instances recorded that will help in understanding a figure such as figure 6.12.	Chapter 6, Section 6.4.2.2, Page 155	Addressed. The large file of raw data was made available through a Google Drive link: https://drive.google.com/drive/folders/1AC4Wf0pc3LabPaBsxbbbdWJjqq1vZe_3?usp=share_link However, the file has been compressed and made available as Appendix C.
30	Figure 6.13. The differentiation between the level of adaptation needs to be revised at the moment there are two poor adaptation criteria.	Chapter 6, Section 6.4.2.2, Page 156	Addressed.
31	Figure 6.17 - Revised the order of the legend to either follow from poor to good, or good to poor. At the moment it is mixed up.	Chapter 6, Section 6.4.2.3, Page 158	Addressed.
	Sub question 3		
32	In the discussion section: Consider the following statement: “There are	Chapter 7,	Addressed.

	clearly concerns that while proper design strategies can be made available, without educating communities on how they can be implemented, these strategies will not be beneficial." This statement is not substantiated by the research up to that point.	Section 7.4.1, Page 231	The statement was wrongly placed. It has been shifted to Section 8.4.3.
33	Table 7.7 consider whether the use of a timber shingles really presents high thermal mass. Consider whether building is truly made from high thermal mass materials or rather light weight materials. Considering the context and the figure 7.6. I would reconsider that statement. It seems like a more lightweight structure allowing high levels of ventilation.	Chapter 7, Section 7.2.3, Page 186	Addressed. This statement referred to sun-dried adobe brick. It has been adjusted.
34	Table 7.15 - Why would using local materials have an impact on the strategies to lower indoor heat stress exposure. I would think it fits better with resources.	Chapter 7, Section 7.2.7, Page 194	Addressed. The precedent was designed to adapt to extreme heat. The use of local material reduces the response time in the case the building needs to be adjusted to improve its adaptive capacity to extreme heat. A phrase has been added for clarification.
35	Table 7.21 - Consider how a modular system contributed to lowering heat stress exposure. Clarify.	Chapter 7, Section 7.2.10, Page 200	Clarification: Modular systems improve the flexibility of the building as highlighted in Chapter 6. A flexible building is easily adjustable to allow for cooling in this case.
36	Table 7.23 – Why would PV cells be addressing overheating. Reconsider the tables that are generated.	Chapter 7, Section 7.2.11, Page 201	Addressed. This has been shifted to 'storms' column.
37	Table 7.26 - Choice to located the Solar panels and Solar PV panels.	Chapter 7, Section 7.3.1, Page 205	Clarification: The solar collectors are in the right category… 'under storms'
38	Table 7.31 - clarify this sentence: "- building adapt to overheating through the use of the air conditioner reducing demand of energy"	Chapter 7, Section 7.3.4, Page 216	Addressed. Sentence changed to 'mechanical ventilation'.

	Outcome of the study		
39	The final toolkit aims to develop a clear set of design strategies, but I missed the opportunity of conveying the level of constructability, affordability, etc. in it (which would have been truly valuable).	Chapter 8,	Clarification: The aspect of evaluating the suitability of the strategies (constructability, affordability, etc) was meant to identify the most relevant strategies for the study area. The strategies which made it to the toolkit passed the suitability test, meaning they have acceptable constructability, affordability, etc. levels.
40	One important aspects that is less clear, how did the initial assessment of the informal settlement inform the toolkit? At the moment this was unclear and possible opportunities or leverage points were not highlighted.		Clarification: The assessment identified the vulnerability of the informal settlement to guide on the focus areas of the study. The strategies in the toolkit address those vulnerabilities as identified at Msunduza. For instance, the settlement poorly adapts to the impacts of flooding, hence the study considered precedents which address flooding impacts, and some of those strategies (relevant to informal settlements) made it into the toolkit. Section 8.2 and Table 8.1 clarifies the connection of the results from the first three sub-objectives.
	Language and academic rigor:		
41	At the start of the document: Note the document that is submitted for PhD degrees are titled Thesis documents not Dissertations.	Cover Page	Addressed. The comment has been addressed. The document has been titled as a 'Thesis'.
42	Fix the citations placement on page 43: "The connection between resilience and sustainability has been explored in an attempt to find measures for addressing unexpected	Chapter 2, Section 2.5.1, Page 43	Addressed. The citation placement has been fixed.

	changes and interruptions in urban context (Ahern, 2011) by several authors, with the aim of unraveling their commonalities and differences to determine whether they complement each other, or if they are two separate concepts (Ahern, 2011; Dovers, 1996; Marchese et al., 2018; Zhang & Li, 2018).”		
43	On page 85 - check the capitalisation of the sectors (bottom of the page), I would not capitalise sectors.	Chapter 3, Section 3.3.4, Page 85	The comment has been addressed.
44	Check the references on page 93 and 94 to the NCCP etc. The in-text references are incomplete.	Chapter 4, Section 4.3, Page 93 - 94	Clarification: NCCP is an abbreviation of National Climate Change Policy, and it has been referenced as MTEA (2015)
45	On page 120 a vulnerability report is mentioned without provide adequate references. This makes it difficult for the reader to follow up.	Chapter 5, Section 5.4.1, Page 120	Addressed. The report has been referenced.
46	On page 131 - Add reference for press and pulse disturbances	Chapter 6, Section 6.2.2, Page 131	Addressed. The reference has been added.
47	On page 132 - “This history is adapted from a report titled, ‘A Brief History of Urban Development and Upgrading in Swaziland’, written by Lowsby and De Groot (2007) and verified by the Ministry of Economic Planning and Development (Government of Eswatini) in the same year.”This sentence does not make sense, did the Ministry verify the report in 2007?	Chapter 6, Section 6. Page 132	This comment has been addressed.
48	Page 141 - The maps need north arrows and scale bars.	Chapter 6, Section 6.4.1.1, Page 141	Addressed.
49	Page 145 - What is meant with “Busiest blocks “in the formal selection. Clarify or define more accurately.	Chapter 6, Section 6.4.1.2, Page 145	Addressed. The sentence has been rephrased.
50	Figure 6.8 - The legend is incomplete - the formal roads are not shown.	Chapter 6,	Addressed.

		Section 6.4.1.6, Page 150	All the roads within Msunduza, both formal and informal, are highlighted.
51	Page 151 Section 6.4.2.1. Edit the plurals of the building types/typologies.	Chapter 6, Section 6.4.2.1, Page 151	Addressed.
52	Page 177 - Consider the word local and international. It is not reflected the location of the different precedents correctly.	Chapter 7, Section 7.1, Page 177	Addressed. The sentence has been rephrased.
53	Page 180 - Consider the word choice “keep a building alive” is that the correct term?	Chapter 7, Section 7.2.1 Page 180	Addressed. The phrase has been removed.

Revisions made as per comments from Examiner's Reports.

Date: January 2024

Examiner 2: Prof Claudia Loggia

Comment		**Section (Chapter, Section, Page no)**	**Action**
1	Perhaps the candidate could have analysed more in detail the legislative and policy framework on informal settlement upgrading. More in particular, I'd recommend looking at community-led approaches to informal settlements upgrading.		Noted. This has been included in the suggestions for further research in Section 9.4.
2	Perhaps, I would recommend a slight change in the title "Design Strategies **for** Informal Settlements towards Climate Change Adaptation in Eswatini"	Cover page	Addressed. The title has been changed as recommended. See title page.
3	Page 83: A Manifesto for Climate Responsive Design - please add the reference to the book properly (indicating the authors and year)	Chapter 3, Section 3.3.3.1, Page 83	Addressed. The reference has been added.
4	Page 88: A spelling error in the sentence "The output of the study (toolkit of design strategies) was evaluated through a survey where participants of "focal" groups - its Focus group	Chapter 3, Section 3.3.4.4, Page 88	Addressed. The spelling error has been addressed.
5	Page 123: 'Destruction' of bridges - spelling error	Chapter 5, Section 5.4.4, Page 123	Addressed. The spelling seems accurate.
6	Page 199: this is a quote and you should indicate the page number in reference "The aim of the architects therefore was "to provide the university with their own modular self-building system which would	Chapter 7 Section 7.2.10 Page 199	Addressed. The page number has been added.

	utilise locally sourced and sustainably produced materials and more significantly employ and develop the skills of local people" (Clegg & Sandeman, 2019).		
7	Page 202: El Pozon, Cartagena de Indias, Colombia - can you please add a picture showing the interventions?	Chapter 7 Section 7.3.1 Page 202	Addressed. A section of a blue-green roof module has been added.
8	Page 235 - table 7.44 - spelling error in "fascia boards"- add the s	Chapter 7 Section 7.4.3 Page 235	Addressed.
9	For the mapping methodologies, the candidate should consider also the drone based mapping combined with collaborative mapping, as suggested by paper "A Hybrid Methodology to Map Informal Settlements in Durban, South Africa	Chapter 3 Section 3.3.2 Page 81	Noted. This has been included in the suggestions for further research in Section 9.4.

Revisions made as per comments from Examiner's Reports.

Date: January 2024

Examiner 3: Eugenio Morello

	Comment	**Section (Chapter, Section, Page no)**	**Action**
1	In 2.2.2. On CCA policies: you can eventually enrich this part, mentioning: - the main networks the role of cities (covenant of Mayors and Global Covenant of Mayors - initiated on mitigation and later enlarging on adaptation; C40, 100 Resilience Cities…) and policies (The EU Strategy in 2013); - I suggest including the technical guidance of the EU CoM on adapting buildings to climate change (2023): https:\\eu-mayours.ec.europa.eu/en/adapting-buildings-to-climate-change-EU-technical-guidance	Chapter 2, Section 2.2.2, Page 19	Noted. This has been included in the suggestions for further research in Section 9.4.
2	In 2.3.1. I suggest distinguishing between two aspects: i) location choice: where settlements are built, and this connects to the exposure of people to climate hazards; ii) morphology, i.e. the physical form and material culture of these settlements, typically low-rise buildings, shelters, where the construction technology highly affects the shape of urban morphology, density, street landscapes and blocks…	Chapter 2, Section 2.3.1, Page 22	Addressed. Based on the comment, the title of subsection 2.3.1. has been changed from 'Morphology of informal settlements' to 'Formation of informal settlements' to maintain the idea of the section. The 'location choice (where settlements are built)' is presented in Section 2.3.3, and the exposure to climate hazards is discussed.

Additional data has been made available at:

https://drive.google.com/drive/folders/1AC4Wf0pc3LabPaBsxbbbdWJjqq1vZe_3?usp=share_link

Please contact musamntungwa1@gmail.com to gain access.