RESEARCH REPORT

From linear to circular: advancing resource efficiency in the built environment in remote and arid regions. The case of the town of Hotazel.

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DECLARATION OF ORIGINALITY

I declare that the mini-dissertation, 'From linear to circular: advancing resource efficiency in the built environment in remote and arid regions. The case of the town of Hotazel,' which has been submitted in fulfilment of part of the requirements for the module of Design Investigation Treatise 801, at the University of Pretoria, is my own work and has not previously been submitted by me for any degree at the University of Pretoria or any other tertiary institution.

I declare that I obtained the applicable research ethics approval in order to conduct the research that has been described in this dissertation.

I declare that I have observed the ethical standards required in terms of the University of Pretoria's ethic code for researchers and have followed the policy guidelines for responsible research.

Signature:

Date: 28 June 2024

i. Abstract

The transition from linear to circular spatial economies represents a pivotal shift towards resource management practices in the built environment. This thesis explores the advancement of resource efficiency in residential built environment within remote and arid regions, focusing on the town of Hotazel as a case study. Hotazel, situated in the Northern Cape province of South Africa, serves as an economic hub driven primarily by manganese mining activities. With its arid and remote location, the town faces challenges related to resource management and environmental management. Through a comprehensive literature review and analysis of existing literature, this study investigates the principles of circularity applicable to residential construction in such challenging environments. Key research questions explore the guiding principles of circularity, alternative construction systems aligned with circular economy principles, and strategies promoting resource efficiency.

The findings highlight the importance of integrating circular design practices, enhancing waste management systems, and optimizing resource utilization to mitigate environmental impact allowing for resilience in remote arid regions.

This research contributes to the discourse on circular principles adoption in arid and remote regions, offering insights and strategies for transitioning towards circular spatial economies in the built environment.

Key words: Circularity, circular economy, resource efficiency, built environment, construction techniques, arid regions.

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ii. Definition of Key Terms

Desert: (noun) a waterless, desolate area of land with little or no vegetation, typically one covered with sand as defined by the Merriam-Webster dictionary. (Anon., 2024)

Dry-Arid: excessively dry. Specifically, having insufficient rainfall to support agriculture. (Merriam-Webster Dictionary) (Anon., 2024)

Remote Locations: areas are far away from cities and places where most people live, and are therefore difficult to get to. (Anon., 2024).

1. Introduction and Background

1.1. Background

Rapid urbanization coupled with the swift growth of societies in the world has led to an increased need for housing delivery. In the case of South Africa, the housing supply crisis stems from a variety of interlinked factors. It is not only characterised by limited access to formal housing finance for low-income earners, and system delays in land allocation as well as infrastructure development which further worsen the dilemma , it is also characterised by a fast-paced growing society that is becoming more and more urbanised, but with that token also has to deal with highly unequal and racially stratified settlement patterns, resulting from its apartheid legacy, (Burgoyne, 2008). This legacy has caused the exclusion of some members of society from some sort of service delivery, infrastructure provision and employment opportunities. The right to sufficient housing is well outlined in international human rights legislation, especially in the International Covenant on Economic, Social, and Cultural Rights. It includes everyone's right to a decent quality of life for themselves and their family, which includes enough food, clothing, and housing, with an ongoing emphasis on improving living conditions, (Marutlulle, 2021). Despite the right to adequate decent housing being a recognized right in South Africa, there is still a deficit or housing crisis faced in a number of countries which may be deemed as a global housing crisis. As a result, backyard shelters and informal communities have grown in popularity as temporary fixes for the housing shortage.

Figure 1 Location of Hotazel,(Source: Washington Post,2023)

Remote locations are no exception when it comes to housing supply and delivery issues and these pose unique challenges in the housing sector. The study primarily focuses on Hotazel, a dry and remote town located in the Northern Cape region of South Africa, specifically in the Joe Morolong local municipality which is a part of the John Taolo Gaetswe District Municipality. Hotazel is also forms part of the Gamagara Mining Corridor.

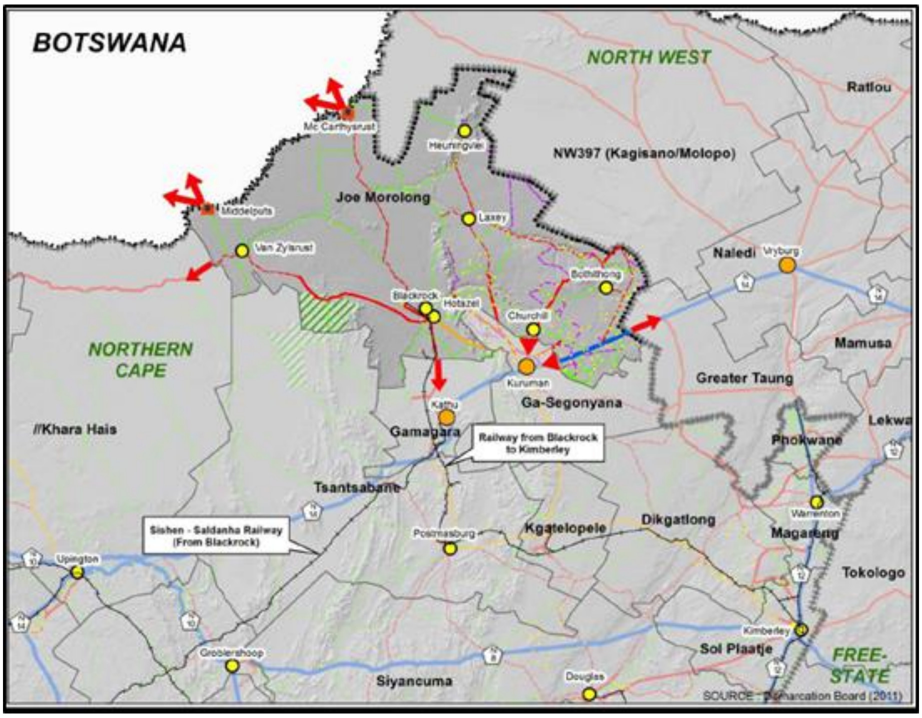


Figure 2 Location of Hotazel within the Joe Morolong Local Municipality,(Source: SDF 2012)

The name 'Gamagara' was originally Gamogara, which is derived from the name of a dry river that ran from Dibeng to join the Kuruman (Anon., 2024). Comprising of 10% of the district's overall territory, the Gamagara municipality is the smallest of the three that constitute it. Mining, farming and business services are the main economic sectors in this area, (Anon., 2012-2024) .In terms of Mining, the Gamagara Mining Corridor is known for its significant mineral deposits, particularly iron ore.

The Gamagara Mining Corridor is known for its harsh aridity and remoteness posing unique challenges for housing development. This may result in limited access to a majority of resources, and this may be tied to costs and viability of the area. The cost and feasibility of sustainable development projects in the Gamagara Mining Corridor may be linked to the area's resource constraints and geographical isolation. The need to transport construction materials over long distances not only increases construction expenses but it also raises environmental concerns such as increased carbon emissions from transportation activities. The economic strain, paired with the negative environmental impact, further underlines the complex balance needed to achieve sustainable development goals in such challenging environments.

The study seeks to unpack the way in which the town can transition from a linear model to a circular model, taking into accounts the challenges the unique environment of Hotazel poses as compared to other growing and developing towns. The study seeks to uncover the approaches taken, which is often the linear approach in housing development projects, especially in remote areas, whereby short-term goals and gains have first priority over long-term sustainability considerations.

1.1.1. Core Concepts

This section provides a brief explanation and defining elements of the crucial concepts of this research. To enhance comprehension that will foster discussions conceptual framework is created by the concise definitions. The terms in this section have a direct influence on the goals of the study.

1.1.1.1. Theoretical Perspectives on Circularity

To successfully adopt the circular economy in Africa, its principles must be adapted to meet the continent's specific growth obstacles. To achieve this, it is essential to first gain an understanding of the concept of circularity. In Europe and other parts of the Global North, the circular economy narrative has mainly emphasized managing waste, enhancing recycling, and reducing expenses, with newer trends highlighting innovations in product redesign and remanufacturing, (Desmond & Asamba, 2019). Several African countries are increasingly transitioning towards greener economies by emphasizing local product design, encouraging reuse and repair initiatives, and minimizing environmental harm and resource depletion (JUST2CE, 2020). Although the discourse surrounding the advantages of a circular economy approach is still developing in Africa, many contend that the continent has inherently embraced CE principles for decades, evidently through its long-standing practices of repair and reuse, sustainable agriculture, and material recovery (JUST2CE, 2020). With that in mind, the concept of circularity is not new; its origins can be traced back to the late 1970s (Marini & di Milano, April 2021). The concept has developed to concentrate on the dynamics of raw materials and resource flows, while also incorporating a wide range of ideas related to closed-loop systems (Marini & di Milano, April 2021).

'Within the realm of buildings, this concept of circularity involves creating a regenerative built environment that prioritizes the retention and refurbishment of structures over their demolition and reconstruction. It entails designing buildings that facilitate easy adaptation, reconstruction, or deconstruction to extend their lifespan. This approach enables salvaging components and materials for reuse or recycling, promoting sustainability and resource efficiency in construction and urban development', (Cheshire, 2019).

Circularity in other terms may be referred to as a design approach that maximises resources utilization and minimises waste production. It is rooted in the principles of nature, whereby there is a closed loop (Figure 3) in all elements, waste is repurposed into nature by becoming useful and creating a closed loop in all resources.

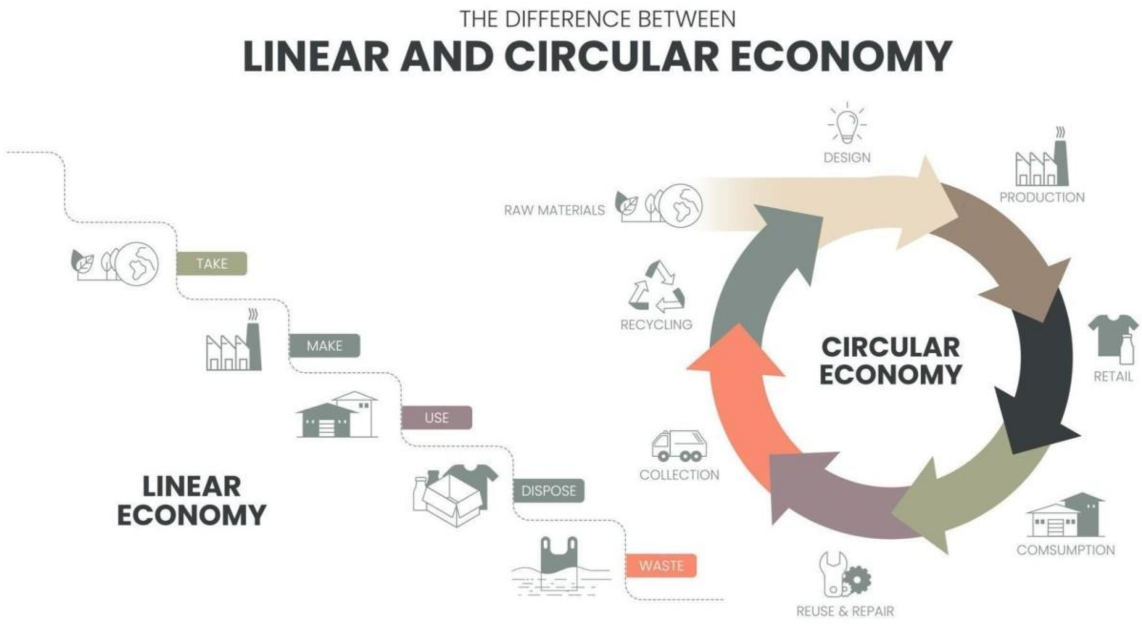


Figure 3 The Difference Between Linear & Circular Economy, (Caroline Macdonald, 2022)

Amongst other industries, mining is a major player in the economy of the Gamagara Local Municipality. Agriculture and community services are also contributors however, mining and agriculture are influenced by market trends and seasonal changes, resulting in the need for workers and housing, which goes up and down accordingly, (HDA, 2015). Mining may be seasonal or only last a certain era ranging from 10years to even 150years, it raises a question of how mining locations can be made sustainable economically, socially, culturally, and environmentally. While the 150year timeframe of mining activity generally exceeds the expected durability of many built structures, it is crucial to emphasize the importance of adaptability and future use in the development of these structures.

The concept of circularity assumes that failure to amalgamate principles of circularity and lifecycle thinking in community building designs as well as material use often leads to resource wastage and exacerbated environmental degradation. This tapered focus on immediate outcomes abandons the broader impacts on ecosystem health, community resilience, and long-term economic viability.

Extending the principles of the circular economy to the housing sector seeks to enhance the sustainability of housing endeavours. This involves employing circular materials, implementing circular design tactics, minimizing waste throughout the housing delivery process, and integrating regenerative strategies into housing design and delivery through innovative methodologies, (Ezema, et al., 2023). Figure 4 illustrates the various policies in Africa, highlighting their diversity and the unique approaches adopted by different nations, reflecting each country's specific economic, environmental, and social contexts, showcasing efforts to integrate circular economy principles into development agendas.

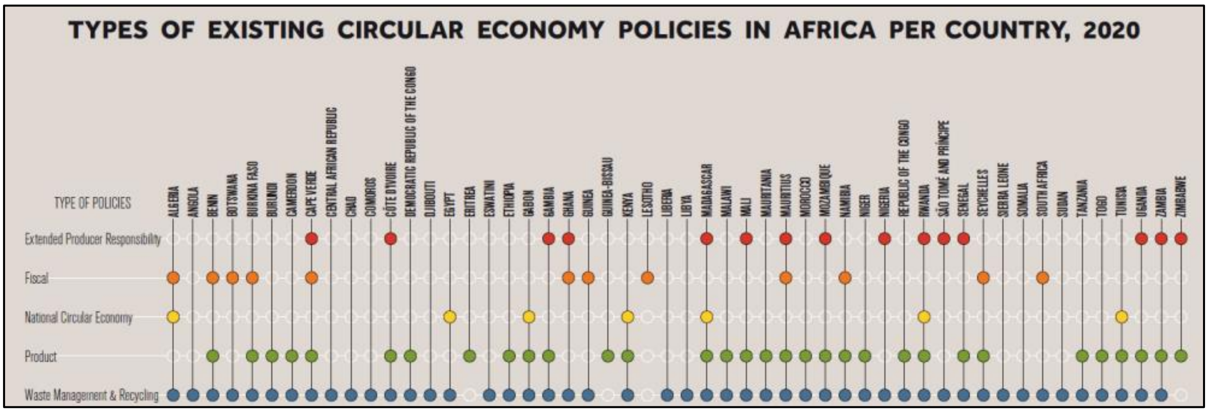


Figure 4 Types of existing circular economy policies in Africa per country(JUST2CE,2021)

While Figure 4 does not explicitly depict the circular economy in the context of the building environment, it provides valuable insights into the broader initiatives and priorities that various African countries are pursuing. In the building and construction industry, the design phase is widely acknowledged as the most opportune stage for integrating sustainable practices, including circular design principles and strategies. The imperative for sustainable building design has grown due to the significant environmental impact associated with construction and demolition activities, (Fatourou-Sipisi, 2021).Projections suggest that embracing circular economic practices could lead to a 4% increase in economic growth by 2030 across European Union (EU) countries. Developing economies in Sub-Saharan Africa however, are facing challenges in adopting sustainable building practices. Therefore, there is a pressing need to accelerate the adoption of Circular Design principles, particularly in the housing sector, to foster sustainable development, (Ezema, et al., 2023).

In a linear design model, products are created or constructed for single lifetime use and disposed of at the end of their useful life, i.e. usually referred to as cradle-to-death.

A circular design however aims to completely eradicate the idea of waste by using materials continuously. The idea is to use materials left over from one product's life cycle as inputs for subsequent product life cycles, in this case referred to as cradle-to-cradle, (Etkins P, 2019). This leads to, demand pressure for new materials to significantly decrease, resulting in resource optimisation. Circular design practices seek to minimise the depletion of the environment brought on by the extraction and processing of virgin materials, as well as the consumption of natural resources.

1.1.1.2. Arid Environments

Terms such as arid, desert, and dryland are widely used alternately without rigorous evaluation and application, (Thomas, 2021). As much as "arid" is used formally to describe drylands, within widely used literature, there is a need to define the differences between the three terms. An overall moisture deficit, which is commonly termed as annual precipitation that is less than potential evapotranspiration, often much less, is usually a defining characteristic of arid regions, (Thomas, 2021). Low soil moisture levels as a result influence both the geomorphic processes that form arid environments and the lives of plants and animals, (Thomas, 2021). Aridity is usually expressed as a function of rainfall and temperature. Aridity is when an area's usable water supply is so low that it interferes with or completely inhibits plant and animal growth and development, (Albahnasawi & Eyvaz, 2023). In arid environments, the primary causes of dry weather are high sun-induced regional temperatures, high pressure from pressure centres, streams along the ocean coast, high mountain ranges and high plateaus, lack of exposure to marine factors, absence of upward air movement, and air turbulence, (Estelaji, 2008).This is the case of the Hotazel whereby levels of precipitation are very low,Figure 5 and the temperatures are relatively high,Figure 6.

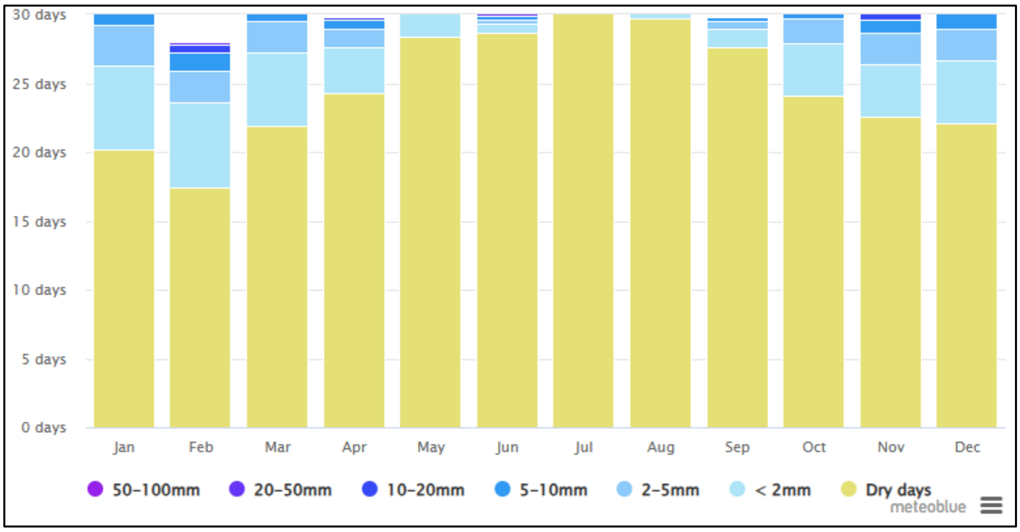


Figure 5 Hotazel Precipitation levels, (Source: Meteoblue,2024)

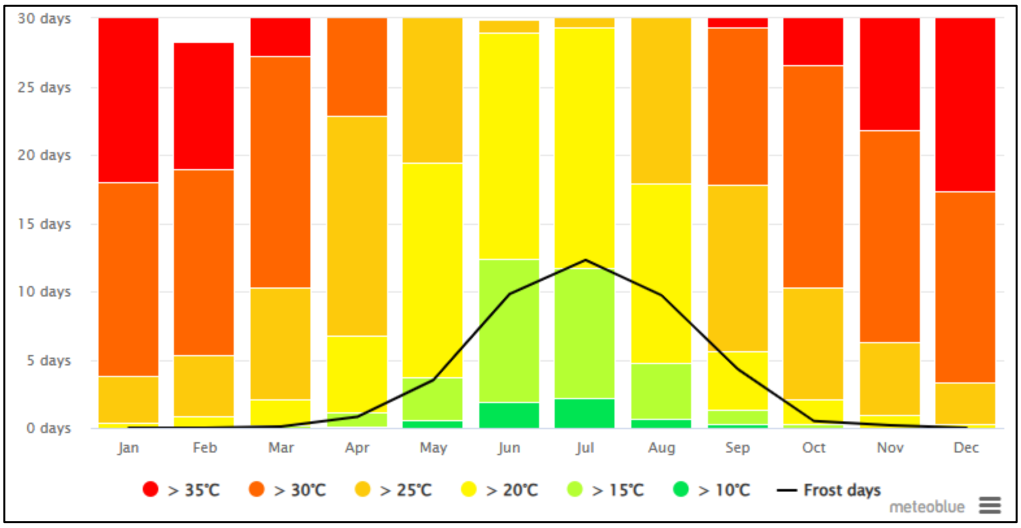


Figure 6 Hotazel Maximum Temperature Levels (Source: MeteoBlue,2024)

Arid regions are often times associated with remoteness due to relatively harsh environmental conditions. The remote communities frequently struggle with long travel distances, harsh weather, and a much slower regional development than more populous areas within the same nation, (Cloete, 2009).In the case of Hotazel, communities travel to the larger towns which are Kuruman and Kathu,these are both economic nodes and are 62km from the town of Hotazel,Figure 7.

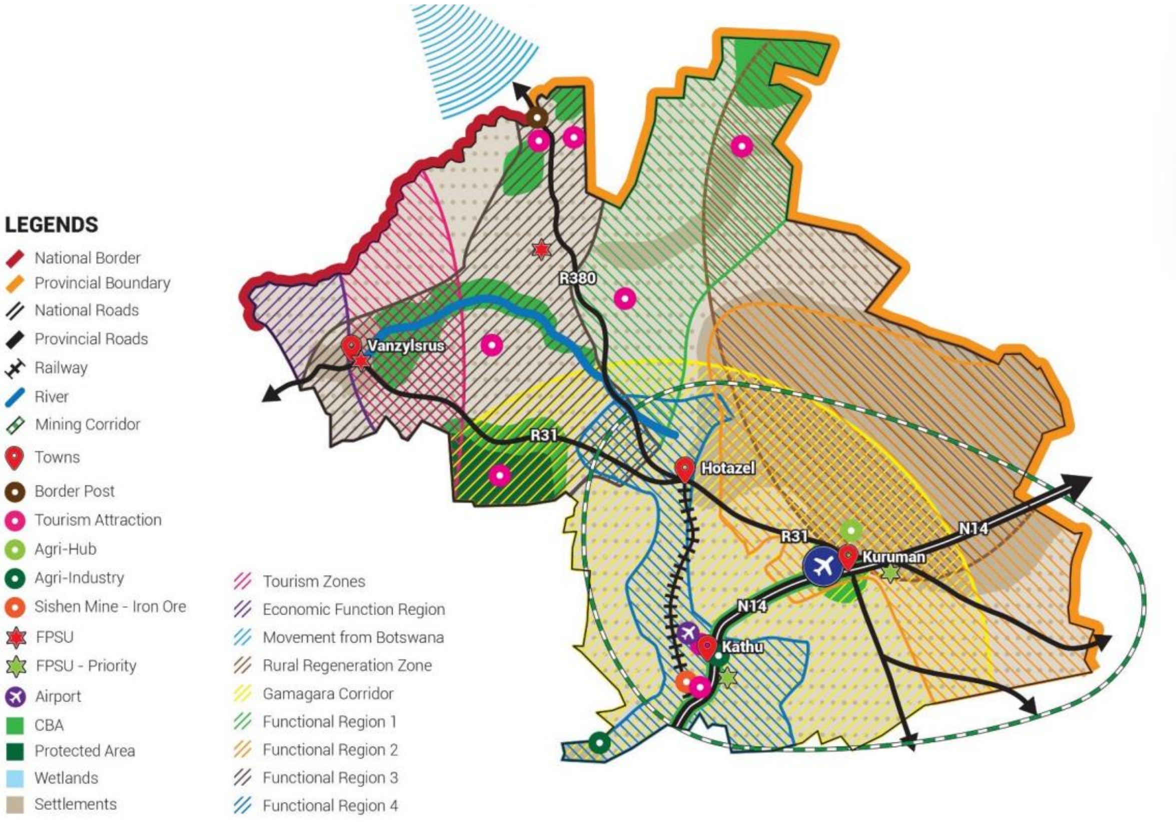


Figure 7 Economic Nodes Closest to Hotazel, (Source: SDP 2023).

Deserts on the other hand are usually defined as areas that receive very little precipitation. While individuals may use terms like hot and dry to describe deserts, this does not give a full view of what these are, (Zappe, 2024). 'They are arid ecosystems that receive fewer than 25 centimetres of precipitation a year,' (Zappe, 2024). Extreme aridity is the common factor throughout all deserts; water is only freely accessible for brief periods of time after some rain showers. Using these definitions, the town of Hotazel would be defined as an arid region due to its high sun-induced regional temperatures.

'Drylands are characterized by physical water scarcity, often associated with land degradation and desertification', (Solowey, et al., 2013). 'They are characterized by the Aridity Index as shown in Figure 8 . 'They are arid and semi-arid areas where evapotranspiration exceeds rainfall for some parts of the year but where there are still opportunities for livestock raising and seasonal cropping', (Solowey, et al., 2013).

	Climate type	**Aridity i**
Dry land subtypes	Hyper-arid	AI < 0.05
	Arid	0.05 ≤ AI < 0.2
	Semiarid	0.2 ≤ AI < 0.5
	Dry subhumid	0.5 ≤ AI < 0.65
Non-dry lands	Humid	AI ≥ 0.65
	Cold	PET* < 400 mm

Figure 8 Dryland Aridity Index, (Murat Eyvaz,2022)

The features of arid regions, as covered above, impact the social framework and means of subsistence of those residing in drylands and arid areas by altering their choices on which sources of income to pursue (Cloete, 2009).

In order to formulate precise diagnostic assessments of possible transition strategies, it is important to categorize the study within a clear framework. By delineating the other terms that can be confusing in the study, the research can take comprehensive evaluations of where the study falls.

In conclusion, the study area, Hotazel, falls within an arid region. This is characterized by the environmental context within which the town fall and these are the water scarcity and climatic conditions typical of arid regions. Understanding the geographic framework of the town is important for informing the scope of the study, tailored to the unique demands of arid regions. The unique demands of arid regions necessitate the development of practices that promote resource efficiency and circular principles. By addressing these challenges, the research aims to identify strategies that not only enhance the resilience of the Hotazel community but also ensure the sustainable use of resources in a manner that aligns with circular economic objectives.

1.1.1.3. Resource Efficiency

Over the progression of years, resource efficiency and circularity has been promoted by the United Nations, together with the European Union which launched a road-map to a resource-efficient Europe, (Van Ewijk, 2018). Resource efficiency has been described as enhancing economic performance and lessening the demand on natural resources by making effective use of them, (EC, 2011),while the United Nations has outlined resource efficiency as the process of mitigating environmental impacts coming from the production and consumption of resources throughout their lifecycles making certain that the management of natural resources is carried out from production to consumption. Resource efficiency improves human means of subsistence while preserving the planet's ecological equilibrium (UN, 2010). Resource efficiency contributes in preventing ecosystem collapse, deterioration, and depletion (Van Ewijk, 2018).

The town of Hotazel being predominantly a mining town that is not only arid, but also remote, environmental resources are vulnerable. The risk of resource depletion and environmental degradation is faced in this town, due to its reliance on finite resources like water. Its dependency on an industry that has high environmental footprints like mining,Figure 9, exacerbates the need to implement resource efficiency measures to ensure that ecological impacts are reduced.

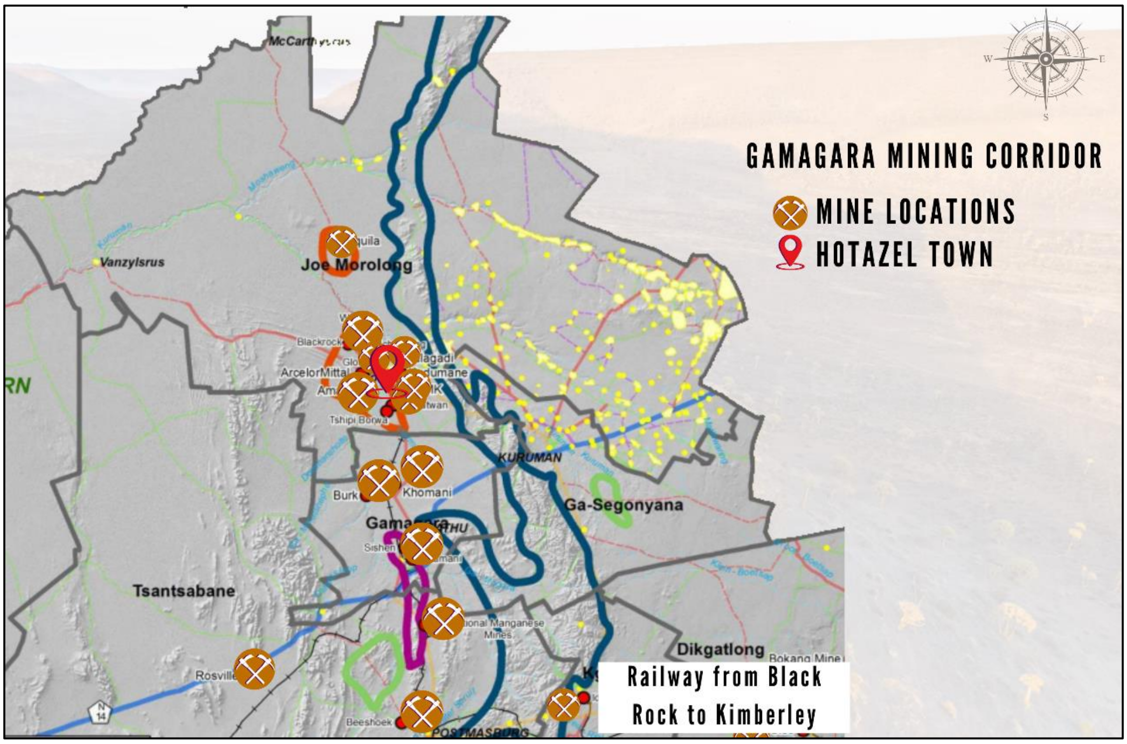


Figure 9 Mining Corridor, within which the town of Hotazel lies, (Source: Author,2024)

Hotazel is susceptible to extreme climate change including extreme weather changes and water scarcity, therefore resource efficiency may enhance the resilience of the town to such challenges. Prioritizing resource efficiency in communities may lead to improved sustainability and reduced vulnerability, allowing communities to respond more effectively to climate-related challenges. Implementing strategies that promote resource efficiency could be instrumental in enhancing the capacity of the town of Hotazel to withstand and adapt to the pressures of climate change.

1.2. Research Problem

Unlike major cities where housing markets develop more naturally and organically, often involving historical master planning, mining towns are usually predominantly designed with a specific purpose to cater to the needs of the mining companies operating in the areas, (HDA, 2015). This results in the housing markets in each town being primarily influenced by the business strategies of mining companies, rather than following the typical dynamics seen in more traditional housing markets.

The housing challenges in Hotazel, pose a hurdle to the development of the town. In light of the finite lifespan of the mine operations, Table 1, it is imperative for the town to transition towards a more sustainable model. The impending closure of mines provides a need to re-evaluate residential infrastructure solutions to accommodate potential changes in population dynamics, resource availability and social and economic activities.

Mine	Nchwaning	Gloria	Mamatwan	Wessels	UMK	Kgalagadi Manganese	Kudumane	Tsipi Borwa
Reserves	107mt	68.3mt	Unlimited	Unknown	41.3mt	Unknown	112.5mt	248mt
Lifespan of the mine	45years	Unknown	Unlimited	Unknown	18years	Unknown	45years	165years

Table 1 Lifecycle of the Mines as predicted by SMEC calculations in 2013, (Source: Author,2024)

Currently, the main economic indicators in the Gamagara Municipality are mining, game farming and business services, (Basson & Rademeyer, 2018). Despite the anticipated closure of smaller mines within the next two decades, the mining reserves in the region are projected to endure for a 100 century at current production levels, specifically in the case of manganese mining is expected to persist for another hundred years, (Rademeyer & Basson, 2018). As mining activities expand in the region, the population living in and around Hotazel is predicted to also increase, necessitating the provision of housing for the growing community.

Indicator	Gamagara Municipality	Joe Morolong Local Municipality
Main Economic Sectors	Mining, game farming and business services	Eco-tourism, agriculture, mining and community service

Table 2 Economic Indicators in the Region, (Source: Annelien Basson,2018)

In the 2014/2015 Integrated Development Plan (IDP), the municipality identified several challenges pertaining to housing within the municipality, Table 3. These challenges were attributed to a multitude of factors; nevertheless, the identification of these challenges facilitated the development of strategies aimed at addressing and mitigating these issues.

Identified Challenges	Linear Approach
Inadequate sanitation and water services	Reliance on centralized water and sanitation systems leading to resource inefficiency and depletion
Insufficient Accommodation	Limited focus on the housing needs of the community
Backlog of housing supply exacerbated by mine expansions	Reliance on traditional construction methods and slow processes
Insufficient water and sewerage services	Neglected infrastructure development

Table 3 IDP Identified Housing Challenges in the municipality, (Source: Author,2024)

Apart from housing challenges, Gamagara Municipality is also facing significant challenges with bulk water supply and sanitation, (Rademeyer & Basson, 2018). The lack or difficulty in attainment of water is a crucial factor affecting the future development projections of the town of Hotazel. Currently, the water is obtained from groundwater resources, (SDF, 2012).

Transitioning to circularity in the residential built environment would offer a transformative pathway to address the challenges faced in Hotazel. The reliance on linear practices in the town exacerbates unsustainable development patterns currently being faced in mining towns, compromising the town's long-term liveability.

1.3. Research Questions

This section focuses on the core inquiries driving the study in advancing resource efficiency in the residential built environment. The study is guided by one overarching question and two sub-questions.

Overarching Question: How can the residential built environment in arid and remote locations effectively transition from linear to circular spatial economies?

1. **Sub-Question:** What are the principles of circularity that can effectively guide the transition of the residential built environment in its remoteness and aridity?
2. **Sub-Question:** What alternative construction systems align with principles of circularity?
3. **Sub-Question:** In what ways can resource efficiency initiatives be integrated into the residential built environment to promote circularity in arid and remote areas?

By examining these questions through a wide lens, this study seeks to create insights, conclusions and recommendations that can accurately inform industry practices and community ideas aimed at transitioning from linearity to circularity and advancing resource efficiency in the residential built environment in remote and arid regions.

1.4. Research Aims & Objectives

The study aims to address and examine the interconnectivity of environmental, social, and economic factors shaping the residential built environment. In addressing these areas, the study potentially contributes to advancing the understanding the residential built environment in remote and arid regions. The objectives of the study are tabulated below:

1. Identify and analyse the key concepts of circularity that would be applicable to the transition of the residential built environment to a circular model.
2. Assess the alternative construction systems and methods aligning with the principles of circularity.
3. Examine strategies and practices promoting resource efficiency in the built environment in arid and remote regions focusing on transitioning from linearity to circularity.

AIM	OBJECTIVES
To develop and analyse the strategies that enable the transition from linear to circular spatial economies, allowing for enhanced resource efficiency.	1. Identify and analyse the key concepts of circularity that would be applicable to the transition of the residential built environment to a circular model. 2. Assess the alternative construction systems and methods aligning with the principles of circularity. 3. Examine strategies and practices promoting resource efficiency in the built environment in arid and remote regions focusing on transitioning from linearity to circularity.

GUIDING QUESTIONS

1. What are the key concepts of circularity applicable to the transition from linear spatial economies to circular spatial economies?
2. What are the alternative construction systems that are aligned to circular principles?
3. What are the current industry practices in the residential built environment of Hotazel?
4. Why is there a need for the transition from linearity to circularity?
5. What are the key patterns identified in the analysis of the literature review?

Table 4 Aims and Objectives of the Study, (Source: Author,2024)

1.5. Limitations, Delineation and Assumptions of the Study

1.5.1 Gaps and Limitations

It is vital to acknowledge the opportunities and constraints that come with the study. These provide a fundamental context to the scope of the study. Highlighting the limitations, delineations and assumptions of the study, provides a more reliable outcome in terms of findings and applicability of the study.

1.5.1.1 Limitations

The findings of this research are dependent on secondary data. Relying solely on secondary data to come up with conclusions and recommendations may create biases and some discrepancies in information received and analysis to be carried out. There is also a risk of generalising due to the limited availability of information. The study is limited to a certain period due to the reliance of data obtained in a certain period.

1.5.1.2 Delineations

Delineating the scope and boundaries of the study is important in this study to ensure that there is a clear definition of what the study includes and excludes. Objectives of the study have been highlighted in 1.4. The geographical scope of the study is the Hotazel town located in the Joe Morolong Local Municipality located in broader context of the Gamagara Municipality.

1.5.1.3 Assumptions

With the overarching question of this study being '***How can the residential built environment in extreme and remote locations effectively transition from linear to circular spatial economies?***', the assumption is that circularity is a more recommended and preferable model than linearity. It is assumed that to create a better environment, communities should shift from the current linear models to circular models. Though there may be communities where this has been implemented and achieved, this assumes that the findings are universally relevant which may deem challenges and opportunities ideal for Hotazel due to matching regions i.e. remote and arid locations. This implication overlooks traits such as culture, economy and policies of the Gamagara Municipality therefore there is a need to critically assess the findings and consider other relevant measures such as culture and economy and not just the aridity and remoteness of the mining location.

2. Literature Review

2.1 Theoretical Framework

This section focuses on the conceptual guide within which the study is built upon. This will provide a comprehensive lens to analyse the steps to transitioning the residential built environment of Hotazel. The key theoretical frameworks covered are tabulated below:

Framework	Description
1.Circularity in the built environment	This framework focuses on the principles of the circular spatial economy, providing a theoretical lens through which the transition from linear to circular models is examined, being a driver for the solutions faced in the residential built environment.
3.Resource Efficiency in the Built Environment	This framework focuses on the strategies aimed at optimizing resource use and minimizing waste. It is however not a standalone framework but it represents components aligned to circularity, sustainability and environmental design.
4.Emerging Trends and Themes in the Literature Review	This section covers a review on literature, precedent studies and reports identifying new developments and construction technologies that are shaping circular models in the residential built environment.

Table 5 Theoretical Framework, (Source: Author,2024)

The conceptual framework for carrying out this study, using the theoretical framework above is illustrated below:

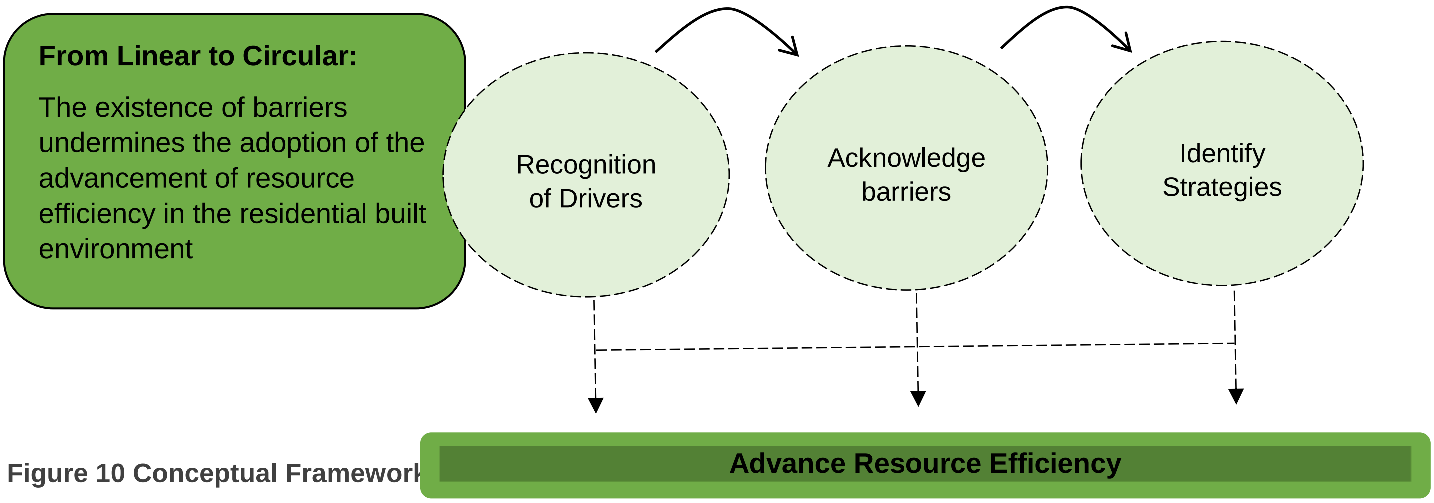


Figure 10 Conceptual Framework

2.2 Point of Departure

The purpose of this research is to explore the effective use of resources in order to enhance circularity within the residential built environment in remote and arid areas. The study concentrates on investigating methods that support resource efficiency, resilience, and sustainability in the context of housing development in these difficult settings. The study aims to investigate how the principles of circular economy can be integrated into building practices to promote effective use of resources. This study will focus on both the efficiency of resource consumption and the circularity of building components, examining how these concepts interact to create sustainable outcomes. By clarifying these distinctions, the study aims to provide an understanding of how to advance both resource efficiency and circularity in the context of arid and remote environments.Material source, energy efficiency, water conservation, waste management, community involvement, and regulatory consequences are important factors considered in this study.

The criteria of the study includes examining methods for maximising energy efficiency in residential structures. The study aims to present an in-depth understanding of the possibilities and limitations connected with enhancing circularity through housing options. The research makes use of the critical review method involving a rigorous evaluation of existing literature.

2.2.1 Circularity in the Built Environment

The construction industry has traditionally followed a linear model, entailing a sequential process of natural resource exploitation by means of extraction followed by usage and culminating in disposal, (Benachio, et al., 2020).This model does not necessarily follow any form of sustainable means like material recycling which leads to wastage of materials and pollution in the environment. With the need and gap in extending the resource lifespan, a new term was created, the 'circular economy.' Over the years, circularity has become jargon that is widely used in the built environment. The recognition that linear practices of resource extraction, utilization and depletion are unsustainable has paved way for the adoption of a circular economy in the construction industry and built environment, (Benachio, et al., 2020).

(Potting, et al., 2016) noted 10Rs addressing the need to extend usefulness in the lifespan of resources, as opposed to the three principles noted by (Mahanty, et al., 2021).The 10 Rs identified by (Potting, et al., 2016) are Reduce, Reuse, Recycle, Refurbish, Repair , Remanufacture ,Recover, Repurpose, Rethink and Refuse. Whereas (Mahanty, et al., 2021) noted Reduce, Reuse and Recycle.

Over the years, researchers have extensively studied and reviewed circular economy practices and its implementation in the built environment and there has been a growth in the research output related to circularity accounting for about 21% per year in the world, (Norouzi , et al., 2021).Regardless of this growth worldwide, its evidence of application and awareness is low in Africa, (Mhlanga, et al., 2022).It has been noted that the relatively low awareness is linked to material selection and in a study, (Rahla, et al., 2021) revealed that Africa contributed only 2% of the publications determining circular economies in the built environment. Researches have also shown that the concept of circularity remains unclear in the context of African countries, further studies claim that the concept of circularity is yet to show some tangible actionable results as the concept becomes more popular (Rweyendela & Kombe, 2021).

While the shift and transition from linearity to circularity is a commendable endeavour, the built environment encounters some obstacles stemming from the lethargy from stakeholders and investors to amend their linear practices, (Mhlanga, et al., 2022).Additional obstacles studies have shown are the lack of collaboration amongst stakeholders, adherence to outdated and old stringent building codes, minimal technological advancements and a lack of technological infrastructure, (Antwi-Afari, et al., 2021).The following table shows the number of research sources that identified similar barriers met in an attempt to transition from linearity to circularity:

Research Barriers of Transitioning from Linearity to Circularity	Sources
▪ Lack of collaboration amongst stakeholders ▪ Adherence to outdated and old stringent building codes ▪ Minimal technological advancements ▪ Lack of technological infrastructure	(Antwi-Afari, et al., 2021) (Matre, et al., 2021) (Hart , et al., 2019) (Cetin, et al., 2021)

Table 6 Identified Barriers of Transitioning from Linearity to Circularity, (Source: Author,2024).

In the literature review conducted by (Mhlanga, et al., 2022),it becomes apparent that stakeholders particularly professionals within the construction industry, play a pivotal role in facilitating the transition from linearity to circularity. Professionals including architects, quantity surveyors and engineers are major players in the transition where they can influence and convince clients and investors in the adoption of the principles of circularity, (Minunno, et al., 2020).

The core goal of the thesis is investigating the possibility of transitioning from the linear model to the circular model in the housing sector. Beginning with the extraction of raw materials, moving through production and product usage, and concluding with disposal in landfills or by incineration at the conclusion of the product's life cycle, is how the linear model depicts the flow of materials. In contrast, the circular model promotes the use and reuse of materials, often described as the "closed loop", (Ellen MacArthur Foundation, 2017). Circular strategies can lead to "narrowing" or "slowing" resource loops in addition to the closed resource loop, improving process efficiency and extending product lifespans (Ezema, et al., 2023).

2.2.2 Conclusion

The study of circularity in the built environment, substantiates its pivotal role on transitioning the transition from linear models. Overcoming some of the obstacles identified in this chapter requires coordinated efforts from stakeholders who are the drivers ,technological advancements a shift in regulatory frameworks and societal norms.

2.3 Resource Efficiency

Resource efficient economies honour the limited nature of the environment (Van Ewijk, 2018).The absence of empirical studies demonstrates that there is no perfect circular economy with 100% resource efficiency in order to support the existence of one. According to (Van Ewijk, 2018) ,the presence of physical and practical constraints, regarding the processing of materials, may be the cause of the prevention of a realization of a 100% resource efficient economy in the built environment.

(Van Ewijk, 2018) studied the **barriers** limiting the attainment of **100% resource efficient economy in the built environment**. The findings are tabulated below:

Indicator 1	Indicator 2	Indicator 3	Indicator 4	Indicator 5
Material circulation requires energy inputs which have environmental impacts.	Material may be unavailable for prolonged durations leading to a point where material demand cannot be solely fulfilled through secondary inputs.	Economic growth increases the demand for the materials, therefore material circulation is inadequate to sustain the growth.	Supply of recycled inputs often fails to align with demand, attributed to technological limitations.	Material circulation involves inherent processing losses.

Table 7 Barriers limiting 100% resource efficiency, adapted from Van Ewijk,2018(Source: Author,2024)

The constraints suggest that solely emphasizing recycling and processing efficiency is inadequate to achieve sustainable outcomes, preventing the depletions of non-renewable resources and adhering to absolute environmental limits.

A number of factors hinder the conventional method of construction from achieving resource efficiency. (Bah, et al., 2018) looks at the challenges there are when it comes to achieving resource efficiency in Africa, and has noted that here is a significant lack of research and practical application related to local and resource efficient materials. Additionally, conventional design and construction methods suffer from a lack of innovation and productivity, (Kedir, et al., 2020).

The first challenge is related to the lack of research and the second challenge is related to the lack of innovation. The lack of capacity to innovate is associated with insufficient investment in digitalization and manufacturing, (Jerome & Ajakaiye, 2019).With the lack therefore, it is imperative for inter-collaborations to take place as well as governmental level incentives to promote new construction methods.

To develop and maintain a competent construction and the built environment sector, organizations must continuously update and retool the workforce and construction techniques in a strategic and sustained manner, Figure 11, (Ene, et al., 2016).

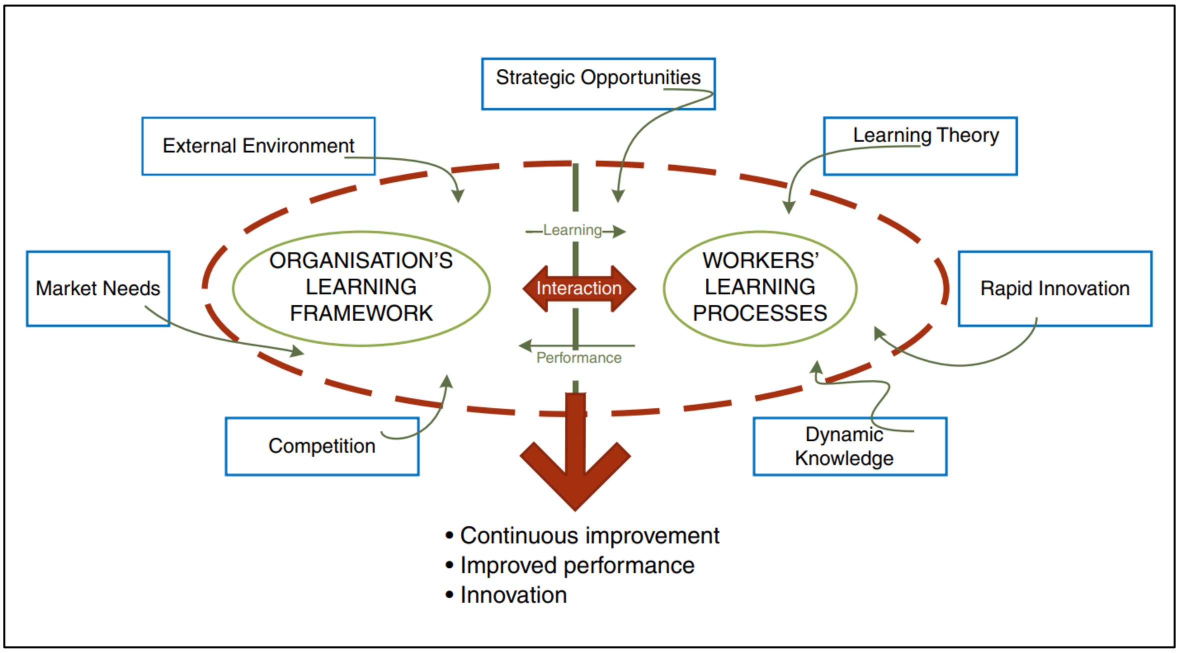


Figure 11 Learning and performance optimisation solution for the built environment, (Source: SASBE,2016)

2.3.1 Material circularity

Resource efficiency and material circularity are related. Material circularity refers to the designing, producing and consuming materials in ways that maximise resource utilization, (Akhimien, et al., 2021).Its concept is to ensure that materials are in use for long as possible, adopting measures of recycling and repurposing, minimizing waste, (Akhimien, et al., 2021).Adopting material circularity measures and practices is fundamental since the need for infrastructure and facilities has expanded, more waste is being produced during construction and destruction, and natural resources are being depleted (Amarasinghe, et al., 2024).

In the case of Hotazel, where there has been an increase in demand for the provision of housing, as there is a backlog in housing delivery, adopting material circularity would be ideal to ensure that there is reduced depletion of natural resources, especially because the town is in a remote area.

In their quest to examine the drivers and barriers to material circularity, and to identify effective measures for bridging the gap between barriers and strategies to enhance material circularity in the building construction industry, (Amarasinghe, et al., 2024) employed three research questions to gather the necessary data:

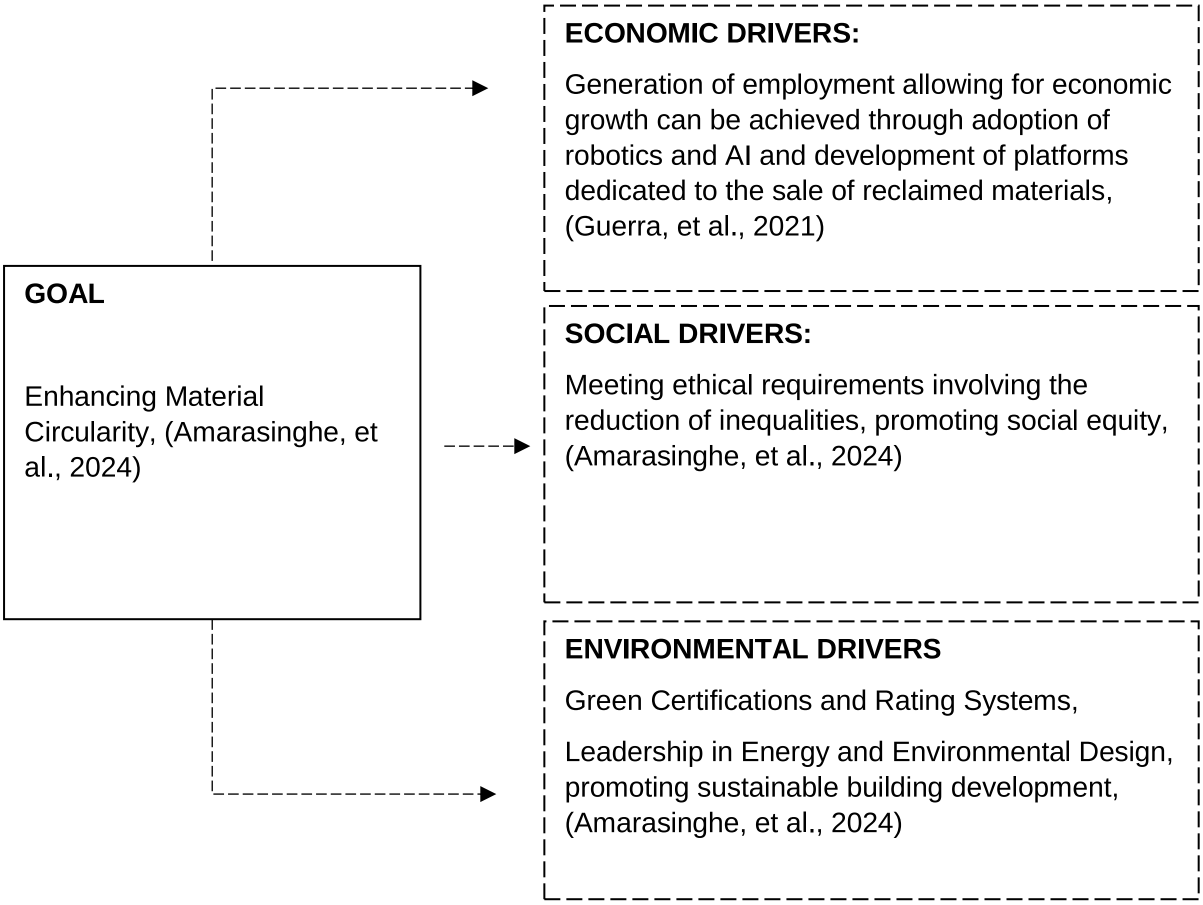


Figure 12 to Enhance material circularity, adapted from Amarasinghe et al.,2024(Source: Author,2024)

Figure 12 supports this study by providing a framework to advance resource efficiency in the residential built environment in Hotazel it covers critical data related to the transition from a linear to a circular system. The findings assist in understanding the extent to which the built environment can effectively transition offering insights into the drivers and barriers of material circularity.

While acknowledging the drivers of material circularity it is also fundamental to identify the barriers to achieving material circularity, in order to be able to strategies towards bridging the gap between the barrier and the advancement of material circularity.

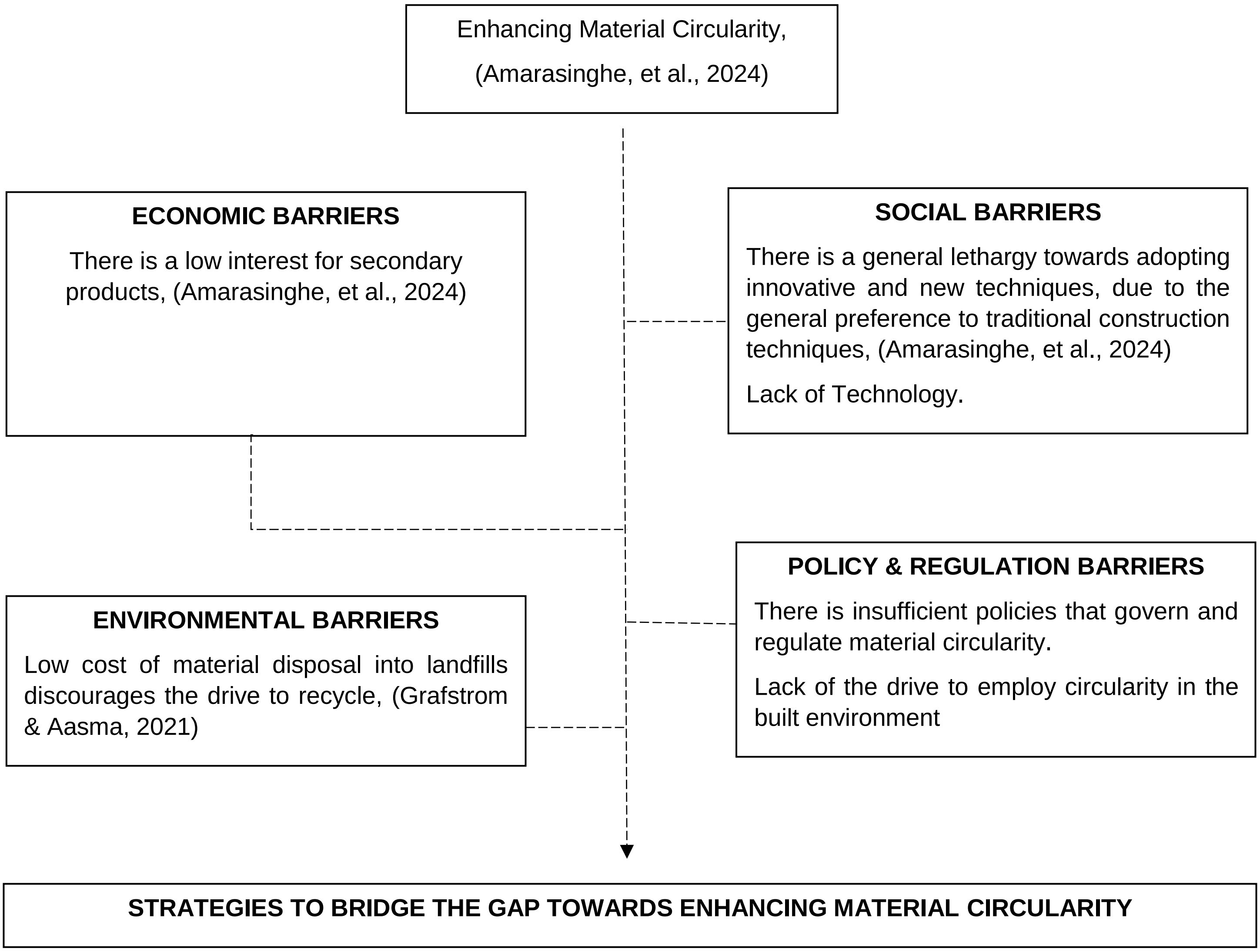


Figure 13 Barriers towards the enhancing of material circularity, (Source: Author)

The study of the factors influencing the improvement of material circularity paves way for devising strategies to enhance material circularity. The insights provided in this chapter from literature reviews provides a roadmap towards material circularity, thereby providing a road map towards the advancement of resource efficiency in the residential built environment.

2.3.1.1 Strategies towards enhancing Material Circularity:

- Introduction of regulations that promote material circularity, (Amarasinghe, et al., 2024).
- Introduction and implementation of incentives to promote and encourage material circularity.
- Employ more researches on material circularity and its implementation
- Fostering collaboration among stakeholders in the built environment together with clients.
- Incorporate digital technologies, (Amarasinghe, et al., 2024).

2.3.1.2 Conclusion

In conclusion this literature review has provided a comprehensive overview of the concept of resource efficiency with a glimpse on material circularity. The application and integration of material circularity principles and measures offers a pathway towards achieving a greater goal of resource efficiency while addressing environmental and community resilience. By embracing and utilizing a holistic approach, Hotazel can serve as a model for the transition from linearity to circularity in arid and remote regions.

2.3.2 Construction Techniques that Enhance Circularity

Ways of achieving circularity for housing supply and delivery, from existing studies, can be attained in different construction techniques which may often feed into each other. (Ezema, et al., 2023). This section looks at the different construction techniques which studies have been noted to lead to a circular environment.

2.3.2.1 Design for Prefabrication

A prefabricated building, also known as prefab building, refers to a structure or a collection of its parts that are fabricated at a location away from the actual construction site and later assembled on-site using self-contained modular units or individual panels, (T. Gunawardena, 2022). In the construction sector, prefabrication has been a long-standing process that takes many different forms, such as drywall systems and structural insulated panels(SIP), pre-stressed beams, prefabricated roof trusses, prefabricated reinforcement cages, and more, over many decades, (T. Gunawardena, 2022).

Building systems that are manufactured offsite may be structured in three different construction systems.

1. Modular (volumetric) construction involves producing self-sufficient units in an offsite location, which are then transported to the site for assembly into a fully integrated structure, (T. Gunawardena, 2022).
2. Panelized construction entails manufacturing flat panel units offsite, which are then transported to the site and assembled to create the entire structure, (T. Gunawardena, 2022).
3. Hybrid prefab construction, also known as semi-volumetric construction, combines both panelized and modular methods. This approach utilizes compact modular units (pods) for areas requiring high serviceability and repetition, (T. Gunawardena, 2022).

Below is an example of prefabricated housing in the context of beach-side forests of the New South Wales Central Coast, Australia. The design challenge included the need for the house to be off-grid and self-sustaining. The house was specifically designed to meet the Bushfire Attack Level ratings required for the fire-risk zone, and these elements were carefully integrated into the design.

Prefab constructions face an issue with public perception, they're easily recognizable as prefab, which has slowed down their acceptance in design and construction circles, (D'Arcy, 2021).

Architecturally designed prefabricated housing holds promise as an alternative solution to the challenges encountered by various stakeholders in the housing industry, including clients, designers, legislators, and builders. While it may not serve as a universal remedy, it presents an alternative to the unsustainable, inefficient, and costly practices prevalent in current housing provision paradigms, (D'Arcy, 2021).

2.3.2.2 Design for Standardisation.

Standardization is the process of consistently producing uniform components or structural layouts and/or sizes, (Norman, 2014).Design for standardization is mostly implemented maximise resource and component recovery at the end of its lifecycle, facilitating recycling and reuse of materials and components. Avoiding material overlap is one of the most important factors in achieving design for standardisation, (Eberhardt LCM, 2022).

From concept to the final product, standardisation plays a significant part in cutting construction costs, (Saphire, 2024). Some of the five major roles that designing for standardization reduce costs are the following:

1. It reduces the cost of design labour. Reducing the amount of options available saves time, effort, and resources in design rather than providing unique, individually developed pieces for each structure.
2. It increases the efficiency of production. Reducing design variances reduces the need for adjustments to staff, equipment, manufacturing, and design time.
3. The likelihood of quality problems is lower than when there is a range of designs. Repetitive practice helps with the design of a and it also increases the component's production as it is learned, which reduces the likelihood of errors.
4. The likelihood of material waste is decreased. Using this strategy makes it much easier and more viable to use materials in the most efficient way possible to reduce waste.
5. It minimises storage and transportation. Less storage space and fewer trucks are required to supply basic items if they can be stacked effectively.

The significance of this notion in development is highlighted by its connection to improving circularity through housing solutions in dry remote regions like the Hotazel. Adopting standardised design principles can be revolutionary in such demanding contexts, where resources are limited and logistics are intricate.

In arid remote regions like Hotazel, where access to raw materials is limited and environmental impacts may be pronounced, maximizing the lifespan of construction materials through standardized design can contribute significantly to reducing waste and promoting circularity through housing supply.

Incorporating design for standardisation into housing solutions in remote, arid regions provides immediate advantages like cost savings and operational effectiveness, however it also supports circularity and responsible resource management, which helps these communities remain sustainable over the long run, (Saphire, 2024).

While there are advantages to designing for standardisation, there are limitations to the phenomenon which may lead to its rejection in society and result in its low success,Figure 14.

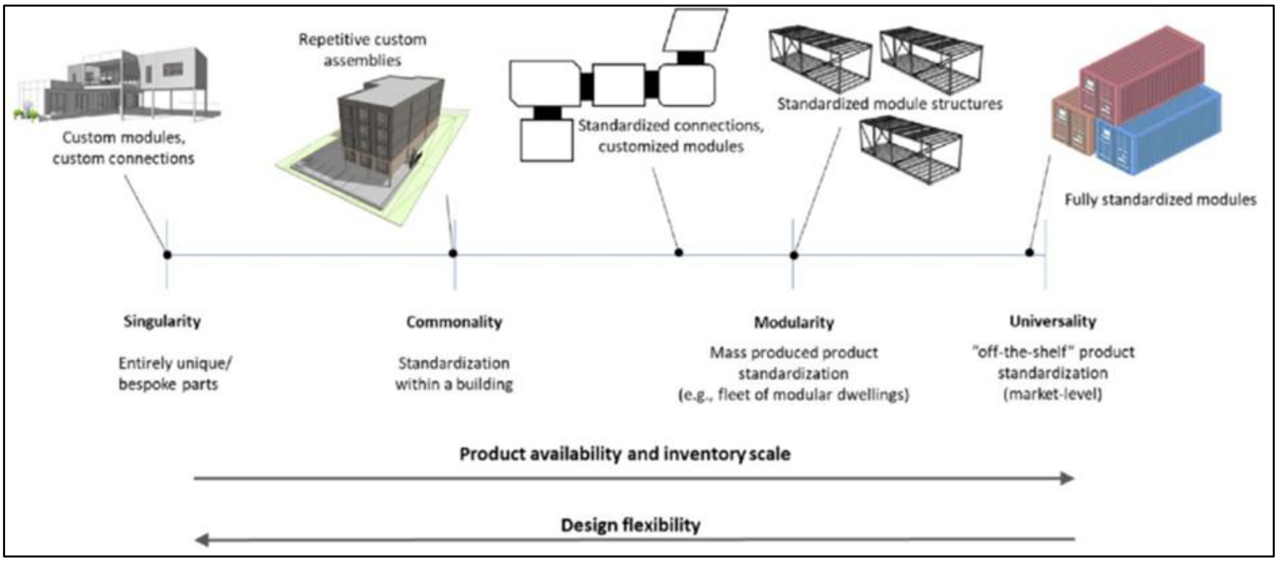


Figure 14 Design for Standardisation vs Design for Modularity, (Christopher Rauch,2022)

From the major roles of design for standardization enlisted above, there are some limitations that may be coupled with the concept and these are listed below:

1. **Balancing Standardization with Creativity**: While standardization may be viewed to impede designers, architects and community members from the ability to be creative, modern approaches to standardization allow for modular designs and adaptable systems that can be customized to meet specific needs (Saphire, 2024).
2. **Lack of Cultural Richness**: An excessive dependence on standard designs can result in homogeneity and market saturation, which can limit the variety of architectural solutions and styles. This may lessen a community's or region's overall architectural richness and cultural variety, (Saphire, 2024).
3. **Undermined Social Cohesion**: Standardized designs may not always resonate with local cultural preferences or architectural traditions, leading to a disparities and disconnections between the built environment and its cultural context. This may be seen as undermining the community's identity and social cohesion, (Saphire, 2024).

While design for standardization offers clear benefits in terms of cost efficiency, resource optimization, and shortened construction processes, it is mandatory and essential to balance these advantages with considerations for creativity, adaptability, and long-term sustainability to ensure successful project outcomes in arid and remote regions like the Hotazel.

2.3.2.3 Design for Modularity

Modular Design is a design technique that divides a single system into several smaller components known as modules (S.Verma, 2022).Design for modularity is used to produce building component modules that are quicker to assemble and disassemble and use less labour through lean manufacturing, (Eberhardt LCM, 2022). Many configurations of an architectural module allow for a large variety of designs to be conceivable. The beauty of modular architecture lies in its ability to add or remove any module without affecting the system as a whole.

Modular Architecture can be used in times of great need with very little time available. As mentioned by the (HDA, 2015), there is a backlog in housing provision in the Gamagara Mining Corridor and considering ways to curb this dilemma may be enhanced by Designing for Modularity.

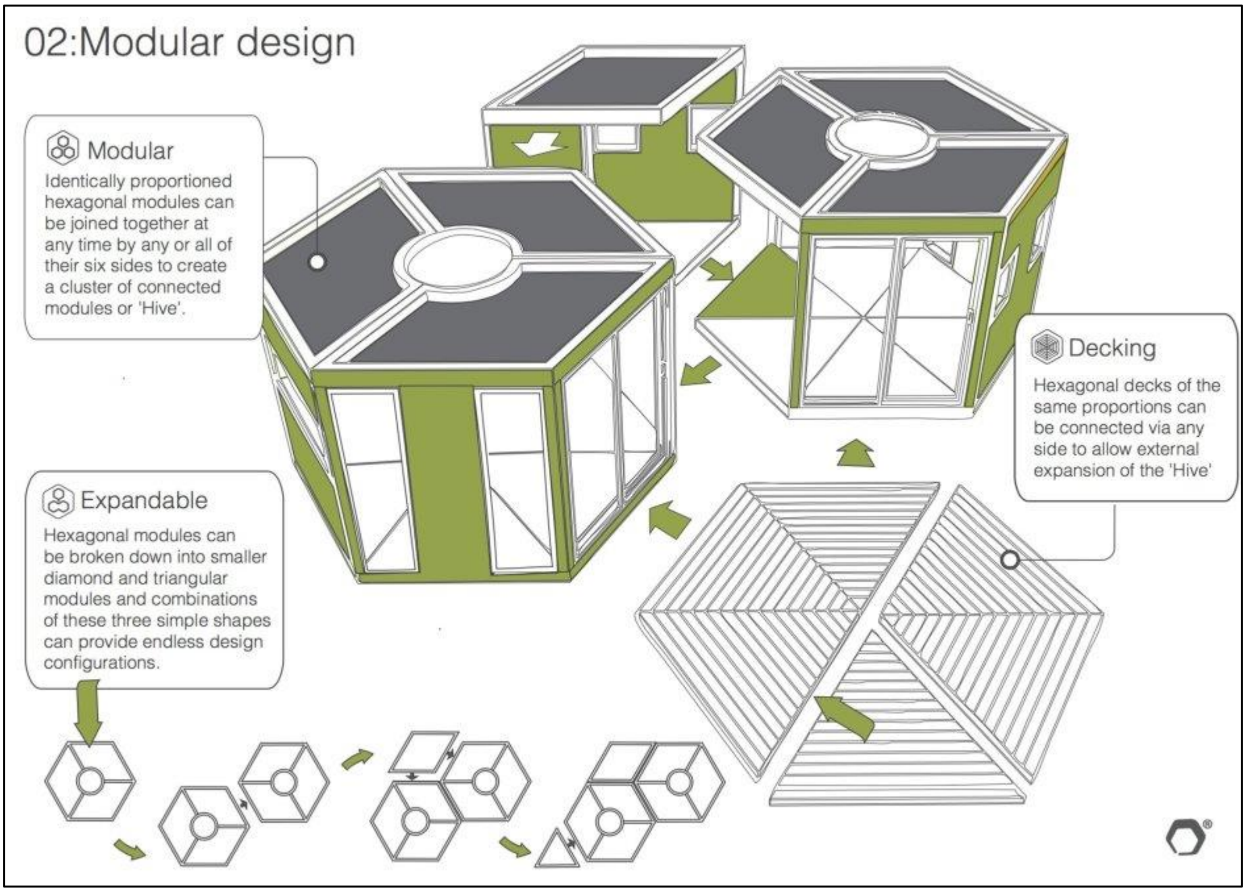


Figure 15 Modular Architecture: Honeycomb Shape, (Google Images,2024)

From the study,Figure 15 , modularity allows for resource efficiency and this is enhanced by the standardised components that can be mass-produced with little waste, which are frequently used in modular systems and are one of the fundamental principles of circularity. Because modular buildings are made to be easily disassembled, their components can be readily removed and reused or repurposed, prolonging the life of materials and lowering the demand for new resource extraction, encourages a circular approach. Reusing existing structures or parts can drastically lessen environmental effect in locations where building materials may be scarce. Designs that adopt design for standardization, prefabrication and modularity through research by design, show results were lesser environmental impact and space efficiency and they also supported the disassembly and recycling, (Ezema, et al., 2023).

2.3.2.4 Design for Reversibility

Figure 16 The BAMB illustration highlighting the principles and goals of Designing for Reversibility, (BAMB,2016)

Reversible building design refers to the process of creating structures that are simple to disassemble or modify without causing harm to the building itself or any of its products, materials, or components, (Durmisevic, et al., 2016). ‘Reversible Building Design enables *resource efficient* repair, re-use and recovery of building materials, products and components since different layers like floors, windows, electric cords, ventilation, inner walls can be accessed without damaging other parts of the building and components can easily be removed or replaced’, (Durmisevic, et al., 2016).

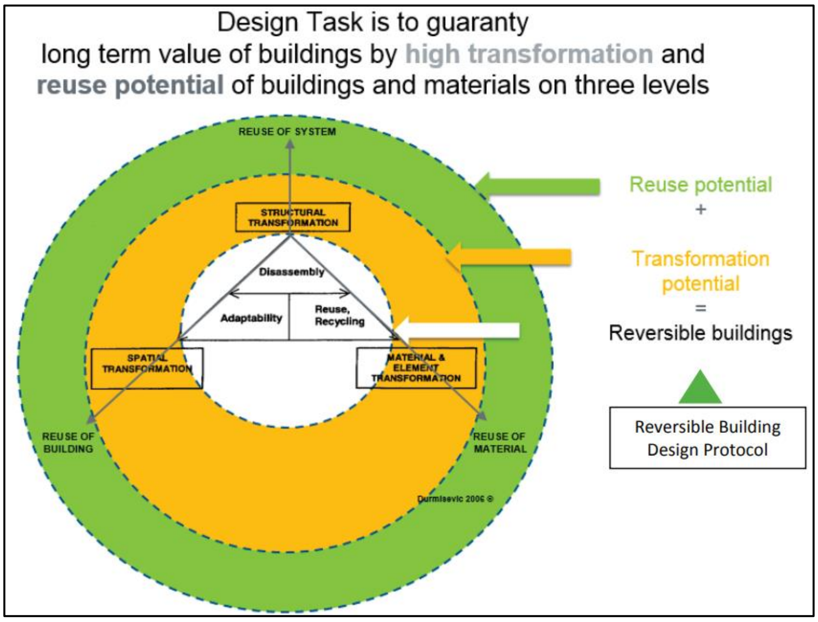


Figure 17 Three dimensions of transformation supported by reuse. Both reuse potential and transformation capacity are measures of reversibility of a building, Durmisevic,2016).

There are three reversible dimensions that can be examined inside a building while investigating the idea of reversible building design, and these may include (1) spatial, (2) structural and (3) material reversibility, Figure 17, (Durmisevic, et al., 2016). Over the course of the building's systems and material life cycle, high value recovery can be anticipated on all three levels provided the building design incorporates all three reversibility dimensions into the final design solution. The three aspects of building change (and related advantages) will be made possible by Reversible Building Design tools, (Durmisevic, et al., 2016).

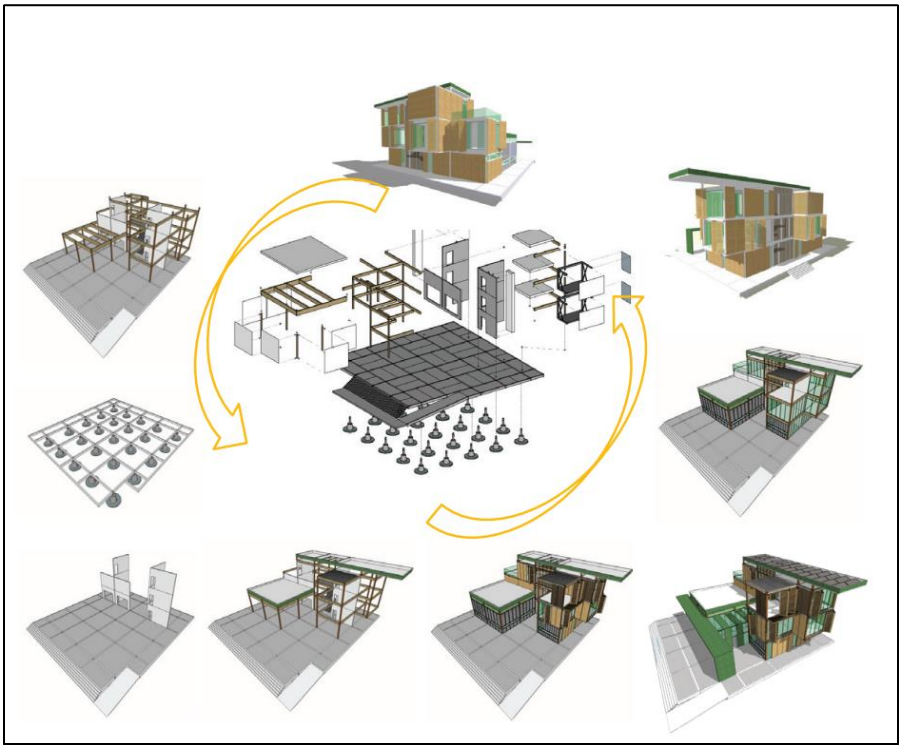


Figure 18 RBD with a focus on high value recovery and reuse of building components, for reuse and reconfiguration, (Innovative Catalogues,2017)

Figure 18,shows an illustration of how high-value recovery can be expected over the course of the building's lifecycle by implementing spatial, structural, and material reversibility into the building's design. Materials and components can be effectively recovered and reused, increasing their market value and reducing waste. By encouraging a closed-loop system where resources are continuously used and circulated, circularity can be achieved.

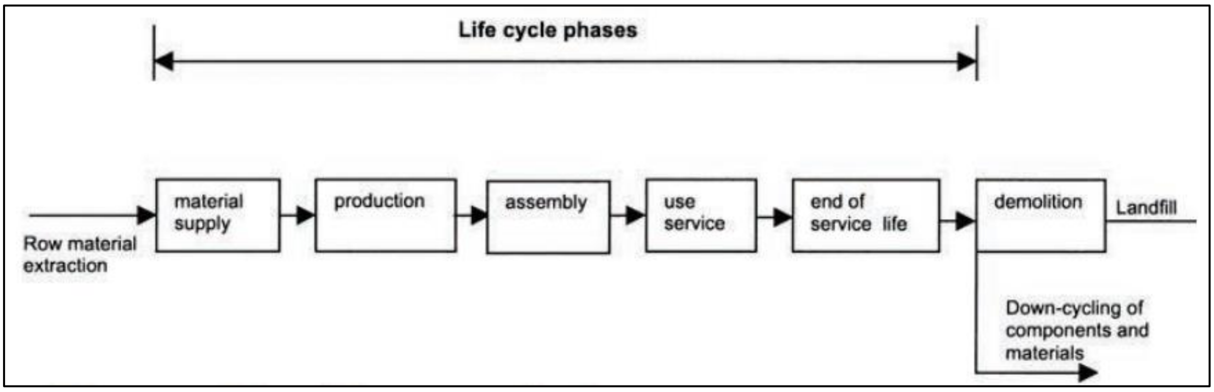


Figure 19 Existing Linear Model, Durmisevic,2016

Figure 19 may be used to depict the linear model of the current housing systems in Hotazel, and Figure 20 may be the new introduced method of how the local area can transition to circularity. The main idea behind reversible architectural design is the distinction between Figure 19& Figure 20 is on closing the shorter cycles of material recovery which have the most positive environmental and economic impacts, (Durmisevic, et al., 2016).

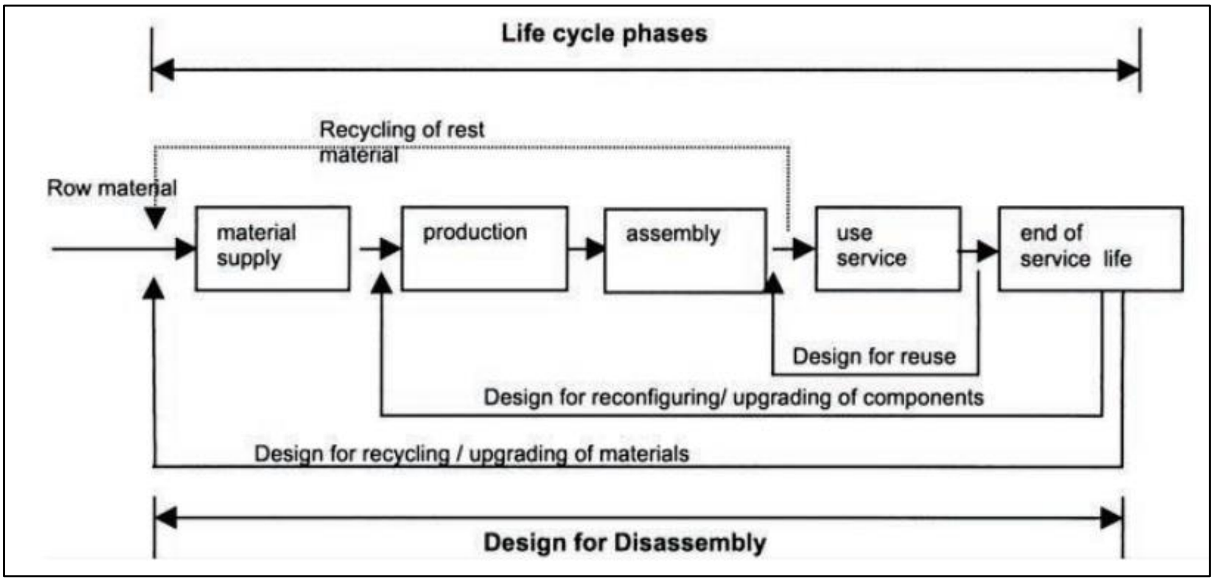


Figure 20 New Cyclical Model, (Durmisevic,2016)

In conclusion reversible buildings by design should be free or have limited waste and enable a circular building sector when implemented with reusable materials, products and components.

2.3.2.5 Design for Reuse

Reusable design refers to the 'direct' repurposing of parts, pieces, or the building itself without the need to add new resources during fresh construction. Integrating design for modularity, adaptability, flexibility, standardisation, and reusability facilitates design for reusability, (Kröhnert H, 2022).

Prioritizing the reuse of existing resources and minimizing the consumption of new materials, reusable design contributes to a more resilient and regenerative built environment that meets the needs of present and future generations. Some of these principles may be relevant for the Hotazel, as it is an already existing town and may make use of these to transition from a linear model to a circular model.

2.3.2.6 Design for Disassembly

One of the most mentioned strategies of circularity or circular economies in architecture is design for disassembly. It is widely mentioned in a number of literatures in various contexts. Design for disassembly mostly focuses on the activities that take place at the end-of-life of buildings. This is to ensure that building elements and components for reuse are recovered thereby minimizing waste, (Ezema, et al., 2023). 'Design for disassembly is defined as a characteristic of a product's design that enables the product to be taken apart at the end of its useful life in such a way that it allows components and parts to be reused, recycled, recovered for energy or, in some other way, diverted from the waste stream', (Durmisevic, et al., 2016).It is non-destructive. It should not be confused with demolition as this is whereby the building is broken down, with little or no attempt to recover any of the constituent parts for reuse, (Crowther 1999). Majority of the buildings are designed in this manner. This is seen in Hotazel as majority of the formal housing is made of brick and mortar and has made use of traditional forms of construction that do not allow for ease of disassembly.

2.3.2.7 Design for Energy Efficiency

By using measures to minimise energy loss, such as lowering heat loss through the building envelope, energy-efficient building design aims to create or renovate structures that can make the greatest use of the energy that is provided to them. Over the years there have been numerous ways that have been implemented in order to come up with energy efficient buildings. A variety of the different parts of the building can be improved to augment this value. By keeping warm air inside or outside the house, more energy-efficient windows, doors, skylights, high-efficiency air conditioners, and furnaces can all help create an energy-efficient home, (Energy Education Encyclopedia, 2024). According to the Energy Education Encyclopaedia, ensuring the building reaches energy efficient levels can be implemented in the following ways:

- Using sufficient amounts of insulation in the roof and walls, paying attention to local codes.
- Applying caulking and weather stripping to the building appropriately.
- Ensuring that premium windows with gas filling and low-e coatings are installed, and selecting the environmentally friendly glazing and window frame materials.
- Setting up high-performing appliances and systems and monitoring their performance throughout their lives.

Reducing the energy consumption of buildings, generating energy locally from renewable resources, and sharing energy by designing buildings that produce excess energy that can be redirected into an advanced grid system are the primary strategies for achieving high-efficiency buildings, (Energy Education Encyclopedia, 2024). Encouraging and promoting the use of less resources, less waste, lifecycle analysis, integration of renewable energy, water efficiency, and community resilience. Stakeholders may build more resilient and sustainable physical environments that support the long-term health of nearby communities in the Gamagara as well as its ecosystems and the circular economy by embracing energy-efficient design concepts.

2.3.2.8 Restorative and Regenerative Design

The terms "regenerative" and "restorative" describe two facets of design that support and harmonise with natural processes, (Ezema, et al., 2023). In order to create an integration of architectural design with natural support systems, such as green and grey infrastructure, and the harmonious interaction between the building and the natural ecosystem. (Ezema, et al., 2023).The difference between restorative design and regenerative is that the former aims to ameliorate and the latter aims to prevent. 'While restorative designs aim at restoring ecological systems to a healthy state, regenerative designs aim at enabling ecological systems to maintain a healthy state', (Brown , et al., 2018).

Incorporating circularity by conserving natural resources, promoting ecosystem health and resilience, integrating green and grey infrastructure, and implementing preventive and adaptive strategies may be a way that the Gamagara Mining Corridor can transition from the linear model to the circular model. Harmonizing architectural design and becoming one with the environment can enhance the creation of circular building environments.

In contrast to sustainably driven designs, regenerative architecture is planned, designed and operated to reverse ecological damage and have a net-positive impact on the natural environment, (Baldwin, 2019). 'The regenerative architecture will allow the construction industry to "do good" rather than merely "less bad",' (Baldwin, 2019).

2.3.2.9 Use of reclaimed or bio-based materials

Hotazel town being predominantly a mining town has a vast number of opportunities for reclaimed materials, useful or not, toxic or non-toxic. Use of reclaimed or bio-based materials into the community enhances circularity in the sense that the design approach, in part or in full, enhances the closing and slowing of the resource cycles by integrating recycled or reclaimed materials or components or by including bio-based or circular materials in a new building.

2.3.2.10 Clay 3D Printing Technologies

'The use of 3D printing technologies has been increasingly present over the past few years in the construction industry. This is for a few reasons, notably it allows the creation of lower-cost houses quicker in order to address the ever-growing housing crisis', (Madeleine, 2023). Additive manufacturing in 3D printing often incorporates a wide range of materials, including industrial by-products like glass and slag, agricultural waste such as rice husk ash and fly ash, as well as recycled materials from construction and demolition, like masonry waste, (Ntakana, et al., 2021).

Like the Gamagara which has a backlog of housing supply, Malawi has a burgeoning backlog of schools and housing, which, according to the United Nations Children's Fund (UNICEF) would require an estimated 70 years to complete using traditional construction techniques. However, with the help of the recently developed 3D printing technology, this can be resolved in less than ten years. In less than a decade, a consortium comprising a Swiss materials company and a UK development financing institution hopes to address and mitigate that issue (Daniel, 2020).

The advantage with this technology is that the homes and schools are easily constructed in hours. This allows for reduced carbon footprints of about 70%. (Gutovic, 2020). In an article about 3D printing, it is highlighted that while the form of housing may be considered as affordable, start-up costs, including the purchase of an industrial sized 3D printer used for constructing houses, range upwards of R1.5 million however using Cobod 3D technology, 1trees aims to print average sized structures – around 46 m² – for under R140,000.

COST OF CONSTRUCTION	CONVENTIONAL	ROBOTIC ARM	% SAVINGS
Foundations	30,129.58	30,129.58	**0.00%**
Wall Plates\ Blockwork	23,414.03	22,088.36	**5.66%**
Roofing	15,951.01	15,951.01	**0.00%**
Finishes	21,934.64	21,934.64	**0.00%**
Electrical	4,666.26	4,666.26	**0.00%**
VIP Toilet	7,938.23	7,938.23	**0.00%**
Tank Stand & Rain Water Goods	4,973.17	4,973.17	**0.00%**
Sub-Total	**109,006.91**	**107,681.24**	**1.22%**

Figure 21 Cost comparison for 3D Printing using robotic arm to conventional construction methods, (Source: Alabi et al,2021)

Figure 21 shows the cost comparison of the use of conventional methods of construction to the use of a robotic arm in 3D printing for a housing subsidy Department of Science and Innovation commissioned at the University of Johannesburg, South Africa as a preliminary comparative cost-benefit analysis. The figure shows the cost of construction by use of a robotic arm as being less than that of conventional methods of construction by 1.22%.

COST OF CONSTRUCTION	CONVENTIONAL	GANTRY	% SAVINGS
Foundations	30,129.58	30,129.58	**0.00%**
Wall Plates\ Blockwork	23,414.03	21,091.36	**9.92%**
Roofing	15,951.01	15,951.01	**0.00%**
Finishes	21,934.64	21,934.64	**0.00%**
Electrical	4,666.26	4,666.26	**0.00%**
VIP Toilet	7,938.23	7,938.23	**0.00%**
Tank Stand & Rain Water Goods	4,973.17	4,973.17	**0.00%**
Sub-Total	**109,006.91**	**106,684.24**	**2.13%**

Figure 22 Cost comparison for 3D Printing using a gantry system to conventional construction methods, (Source: Alabi et al,2021)

Figure 22 shows the cost comparison of the use of conventional methods to the gantry system as being less than that of conventional methods by 2,13%. In both instances where different methods of 3D printing were used, the method is less than that of conventional methods of construction.

These highlighted attributes of 3D printing contribute to circularity in a number of notable ways. Circularity is enhanced through reduced or minimized waste, optimized sustainability of the building materials throughout the building lifecycle as well. While 3D printing is capable of producing multiple components at the same time, using both conventional and recycled materials, and can incorporate a variety of colours, (Ntakana, et al., 2021),it cannot be considered a fully circular construction method due to its reliance on cement-based materials, which are not fully aligned with circular economy principles.

2.3.2.11 Conclusion

In conclusion, the literature covered in this section has shown how the town of Hotazel can possibly transition from a linear model to a circular model. Integration of design principles such as standardisation, modularity, reversibility, reusability, energy efficiency, and regenerative/restorative, offer comprehensive techniques for the transition from linearity to circularity. There are opportunities to address context specific challenges using these principles.

Though there were pros and drivers highlighted, it is fundamental to also highlight the drawbacks or barriers that are associated with the different construction techniques. While modular design may be rooted for and seem suitable for attaining circularity and resource efficiency, it may require large capitals upfront and prior to the commencement of design work.

Reversible design similarly requires upfront investment. Though it may be worthwhile in the long run, sometimes large lumpsums may not be readily available at the commencement of the project. These approaches offer flexibility and resource efficiency; however these techniques may not be suitable if there is not enough investment in infrastructure and technologies available which becomes a hindrance to the need to adopt such practices.

The trend noted in each of the construction technique explored in this chapter is that there may be high initial costs to the projects as they may likely require integration of specialised knowledge and expertise to ensure the success of the projects. The large amounts whether available or not, may discourage investors and lead them to opt for easier solutions which may not necessarily be environmentally friendly or enhance circularity. This may be one of the influences of opting for linear models worldwide.

While there are disadvantages coupled with these techniques, there are also strong advantages. Through cooperative efforts, creative solutions, and calculated investments, Hotazel has the potential to become an exemplary instance of circular development, highlighting the possibility of resilience-buildings and sustainable growth in dry, arid and remote regions and beyond. Instances such as incorporating harmonious architecture with nature through restorative and or regenerative design, restores ecosystems, supports biodiversity, and enhances community well-being. A healthy community is a thriving community. Allowing for the integration of energy-efficient technologies and renewable energy sources helps diminish the need for societies to depend on fossil fuels which will reduce greenhouse effects and gas emissions, promoting energy security in Hotazel.

2.3.3 Emerging trends and themes

In a fast-paced world, with ever growing trends, technologies and shifting societal norms, it is fundamental to study and investigate new inventions and themes in present day times. This helps shape and direct the research and guide what is already being done in the world. Understanding emerging patterns allows us to navigate complexities, seize opportunities and identify challenges, as well as adapt effectively, delving into dynamic terrains that are shaping the trajectory of the global community.

2.3.3.1 Key trends and Supporting Studies in Research of Transitioning from Linearity to Circularity

This section investigates some of the key emerging themes in the literature review of transitioning from linearity to circularity. These themes and trends inform patterns in circularity.

Trend and Themes	Description	Sources
Lack of Collaboration Amongst Stakeholders	The sources have shown that as much as there are drivers towards transitioning from linearity to circularity, there has been a trend of the lack of collaboration to amongst stakeholders and clients, promoting the use of secondary products. This lack of collaboration hinders the promotion and adoption of secondary products, slowing the overall progress toward circular economies.	(Antwi-Afari, et al., 2021), (Hina, et al., 2021), (Rizos, et al., 2017)
Lack of Available Literature on the transition	Of the studies conducted, there is very few literature that cover the effective transition especially in the African countries, amounting to 2% of the literature on transition being from Africa and its contexts. This knowledge gap shown by (Amarasinghe, et al., 2024) presents a challenge to informed decision-making and the application of best practices in these regions.	(Amarasinghe, et al., 2024), (Cetin, et al., 2021),
Lack of Technological Infrastructure	The adoption of circular practices is significantly hindered by inadequate technological infrastructure, particularly in remote and under-resourced regions. Pivotal construction methods that aid circular practices, require substantial investment and technological readiness, which are often lacking. This barrier prevents the scaling of innovative solutions that could support circularity in the built environment.	(Cetin, et al., 2021), (Amarasinghe, et al., 2024),
Lack of Policies & Regulations that touch on circularity	Lack of policies that support circularity resulting in its slow adoption. This regulatory gap leads to inconsistent adoption and implementation of circular strategies, particularly in regions where government support is critical for driving change.	(Amarasinghe, et al., 2024), (Hekkert, et al., 2017), (Milios, 2018)
Adherence to Outdated and old Building Codes	The Existing Building Codes do not support the innovation of circular practices, therefore slowing down its implementation. These codes are typically designed around traditional building methods and materials, limiting the potential for innovation.	(Matre, et al., 2021), (Hart , et al., 2019).
Low drive to transition to Secondary Products	There is limited demand and interests from the clients and public in products made from recycled materials, more especially in the residential built environment. This limited interest stems from both a lack of awareness and cultural preferences for new, rather than recycled, products. Consumer education and	(Grafstrom & Aasma, 2021), (Hina, et al., 2021),

	targeted incentives are required to shift perceptions and drive market demand for circular products.	

Table 8 Key Trends and Themes Adapted from the Literature Review, (Source: Author,2024)

2.3.3.2 Conclusion

The reviews of the literature highlights a number of important drivers, barriers and strategies for the shift from linear to circular in order to advance resource efficiency in the town of Hotazel. A major observation noted in this review is that there are more barriers than drivers for the transition.To tackle these patterns covered in this review, all-encompassing regulatory structures, funding and technological breakthroughs and enhanced collaboration amongst stakeholders in necessary. Addressing these issues will make it possible to successfully implement a circular economy in remote areas like the Hotazel since this is already difficult in larger urban areas.

3. Research Methodologies

3.1. Introduction

The purpose of the study is to investigate and explore how resource efficiency can be advanced in the residential built environment in especially remote and arid regions like that of Hotazel, through the principles of the circular economy. In this section, research design, data collection methods and analysis techniques will be outlined.

The research addresses the following main questions:

Overarching Question: How can the built environment in arid and remote locations effectively transition from linear to circular spatial economies?

1. **Sub-Question:** What are the principles of circularity that can effectively guide the transition of the residential built environment in its remoteness and aridity?
2. **Sub-Question:** What alternative construction systems align with principles of circularity?
3. **Sub-Question:** In what ways can resource efficiency initiatives be integrated into the built environment to promote circularity in arid and remote areas?

3.2. Research Design

The research methodology section for this study describes the research design, data collection and analysis methods used to investigate the topic 'From linear to circular: advancing resource efficiency in the built environment in remote and arid regions. The case of the town of Hotazel.' The section will make use of a comprehensive approach that ensures a thorough analysis and interpretation of data. The research uses a qualitative approach using thematic analysis to investigate secondary data. By using a thematic analysis, a deep understanding of various factors influencing resource efficiency in the context of a circular economy in the built environment is seen.

3.2.1. Data Collection

This study makes use of secondary data from peer-reviewed journals and articles, reports and government publications. The selection of data is based on the following their relevance and link to the circular economy, resource efficiency and the built environment as well as regions similar to that of Hotazel. This data collection approach was chosen to ensure a broad and relevant base of information, given the scarcity of studies specifically addressing circularity in African, arid, and remote contexts.

3.2.2. Data Collection Process

The table below describes the steps undertaken during the data collection process to ensure a comprehensive and systematic collection process:

Process	Description of Process
Literature Search	By use of relevant key words, searches were conducted in peer-reviewed journals, articles and academic sources.
	Sources used: Academia, ResearchGate, ScienceDirect, Google Scholar.
	Keywords used: Circularity, circular economy, resource efficiency, built environment, construction techniques, arid regions.
Criteria	Data selected was selected based on relevance of the study to the research topic and the credibility of the publications.
	Credibility: Peer-reviewed journals and articles, reports and publications.
	Relevance: The selected data focuses on circular economies, resource efficiency and the built environment.
Extraction	Information extracted from the sources is related to the research study through similar themes.
	Extracted Data: Enablers, drivers, barriers and strategies influencing the transitioning form linearity to circularity, advancing resource efficiency in the residential built environment.

Table 9 Data Collection Process for the Study-From linear to circular: advancing resource efficiency in the residential built environment in remote and arid regions, the case of the town of Hotazel. (Source: Author 2024)

3.2.3. Data Analysis

This will encompass a thorough review and analysis of literature, inclusive of research papers, reports, and articles which focus on circularity in general, circularity in housing solutions, sustainable development in mining areas, as well as housing solutions in arid regions which may or may not be limited to arid locations. By collecting data from a variety of sources, the study seeks to construct a framework in order to identify gaps in the studies which will that foster even more investigations.

The analysis also makes use of a variety of mixed methods of research however will particularly make use of the thematic analysis method. This approach encompassing the different types of methods, seeks to achieve an understanding of the factors influencing the transition to circularity. By using the thematic method of analysis, it solidifies the accuracy, relevance and reliability of the research findings, bringing light to useful data and allows for the valuable contribution to development practices.

3.2.3.1. Analysis of Literature

The literature review analysis includes identifying recurring themes and patterns within the set qualitative data. The themes are organized by factors 3.4.1 to 3.4.6 which are economic factors, environmental factors, infrastructural factors, technological factors, expertise and skills, architectural typology and policy and regulatory building codes. By analysing the literature data, the study aims to uncover insights and narratives related to advancing resource efficiency in the residential built environment particularly circularity strategies and implementations as well as sustainable development goals in arid, remote mining locations in Hotazel.

Criteria

Using the data collection process stated in Table 9 the study made use of the following number of sources, (see Table 10):

Source Type	No. of Sources	Example of sources.
Peer-reviewed journals	15	Developing a mine waste atlas for the Northern Cape, South Africa (Koovarjee, et al., 2023)
Industry reports	13	Social Impact Assessment (SIA) scoping report for Hotazel 2 (Opperman, 2020)
Articles	4	Utility scale:10 biggest solar projects in South Africa (Ndlovu, 2024), How mine dumps in South Africa affect the health of communities living nearby (Nkosi, 2018)
Government publications	6	Joe Morolong local municipality, Spatial Development Framework (SDF, 2012), Integrated Development plan for the John Taolo Gaetswe District Municipality (JTGDM, 2021)
Other scholarly sources	6	A critical analysis of housing inadequacy in South Africa and its ramifications (Mahanty, et al., 2021)

Table 10 Number of sources used in the study (Source: Author,2024)

3.2.4. Rationale for Research Methodology

The transition from a linear to a circular economy in the residential built environment represents a critical advancement in achieving self sustenance in remote and arid regions where resources are scarce and environmental challenges are pronounced. This study aims to provide insights into how circularity can be effectively applied to enhance resource efficiency in such contexts. The rationale for the chosen research methodology is grounded in several key considerations:

3.2.4.1. Contextual Relevance

Hotazel, as a case study, exemplifies the challenges faced by arid and remote regions in South Africa. With its reliance on finite resources and the pressures of climate change, understanding how to implement circularity in this context is essential. The methodology focuses on identifying existing literature and secondary data that highlight successful strategies and frameworks applicable to similar environments.

3.2.4.2. Addressing a Knowledge Gap

Existing research on circular economies often overlooks specific challenges faced by remote and arid regions, particularly in the African context. By employing a qualitative approach and thematic analysis of secondary data, this study aims to fill that gap. It critically examines the principles of circularity and their applicability to construction and resource management,therefore contributing valuable knowledge to an under-researched area.

3.2.4.3. Engagement with Existing Literature

A critical reflection on existing studies is integral to this research. Rather than summarizing available data, the methodology emphasizes an analysis that challenges conventional narratives and identifies gaps in knowledge. This approach allows for a more in-depth dialogue on the practical implications of circular economies in specific contexts.

3.3. Study Area and Context

Figure 23 Manganese Mine in Hotazel, (Source: Washington Post,2022)

To be able to answer the research questions it is imperative to understand the context of the study area, Hotazel. As mentioned in chapter one, Hotazel is located within the Joe Morolong Municipality. The Joe Morolong Local Municipality is the biggest municipality in the John Taolo Gaetsewe District, Figure 24. The town is secluded and parched, roughly 48 kilometres northwest of Kuruman. Kuruman and Kathu are the towns that are comparatively closer for purchasing materials and amenities. The three main centres of economic activity in Joe Morolong are Vanzylsrus, Hotazel, and Blackrock, (SDF, 2012),however relying on the towns Kathu and Kuruman which are located in Gamagara and Ga-Segonyana Local Municipalities respectively, Figure 24.

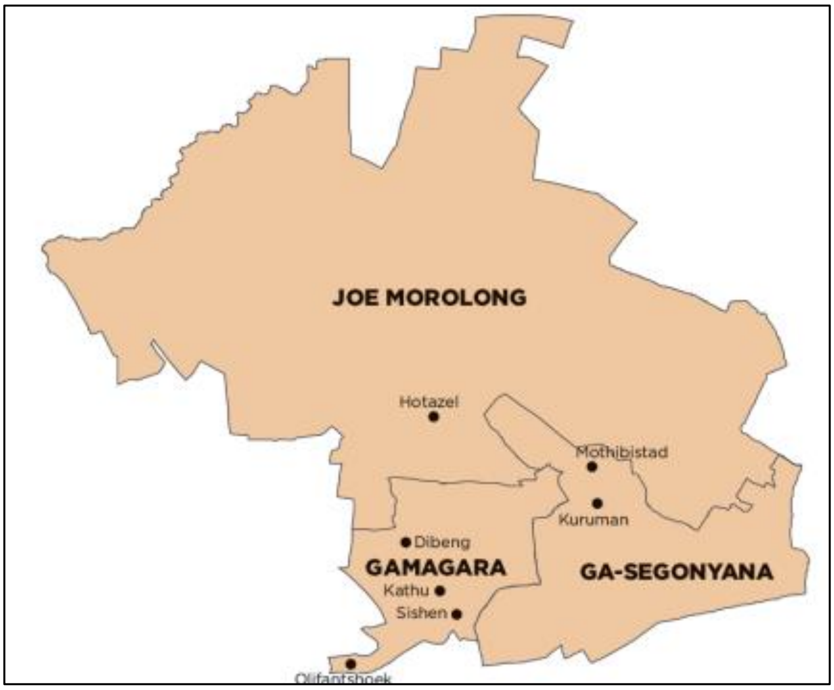


Figure 24 John Taolo Gaetsewe Municipality found in the Northern Cape, (Source: Social Scoping Assessment-Hotazel 2,2020)

It is important to also note that Hotazel lies within the Gamagara Mining Corridor which is where the mining of manganese activity takes place, Figure 25.

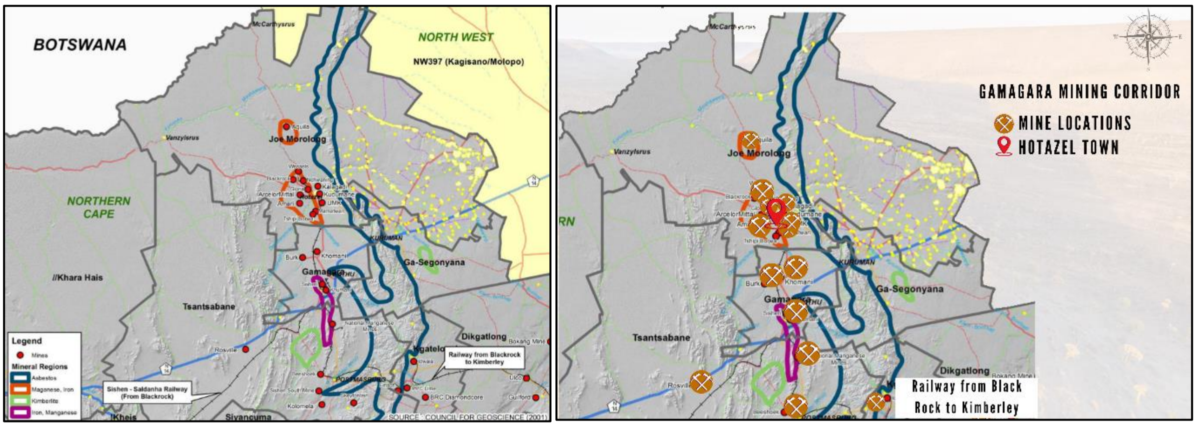


Figure 25 The Gamagara Mining Belt and Mine locations, (Source: SDF,2012)

With the manganese mining activity noted in the region, Hotazel is certain to grow, but it is imperative that the community be prepared for this inevitable growth. The growth is determined by the mining operations, which predict mines will continue operating for about 165 years before their closure, (Basson, 2018). Owing to the substantial mining activity, the Gamagara Mining Belt has been labelled and recognised as a National Asset, (Basson & Rademeyer, 2018).The anticipated growth of the town and region overall, necessitates a proactive approach to resource management. The subsequent sections of the study, delve into the findings of the town in detail, allowing for an analysis of the themes.

3.4. Findings of literature

This section summarizes the findings on the various factors that affect the transition from linearity to circularity in the residential built environment of Hotazel. To ensure the findings align with the study, the research questions used are listed below:

Overarching Question: How can the residential built environment in arid and remote locations effectively transition from linear to circular spatial economies?

i. **Sub-Question:** What are the principles of circularity that can effectively guide the transition of the residential built environment in its remoteness and aridity?

ii. **Sub-Question:** What alternative construction systems align with principles of circularity?

iii. **Sub-Question:** In what ways can resource efficiency initiatives be integrated into the built environment to promote circularity in arid and remote areas?

The findings have been systematically structured and presented into distinct thematic areas. This approach ensures a coherent presentation of data that aligns with the overarching research questions and objectives. The thematic areas to be stated in Table 11 as follows:

Factors	Count	Description
3.3.1 Economic Factors	Financial impacts	Stating the barriers and incentives related to circular construction practices in the study area.
3.3.2 Environmental Impact	Ecological impacts	Stating the implications of the current nature of the environment of the town.
3.3.3 Infrastructural Factors	Physical and logistical impacts	Stating the factors that affect the adoption of circular construction principles.
3.3.4 Expertise and skills	Qualifications	Stating the availability of skills enough for the implementation of circular construction
3.3.5 Architectural Typology	Preferences and dominant typologies	Stating the design and structural characteristics of the town.
3.3.6 Policy, Regulatory and Building Codes	Current policies	Stating the existing regulations and building codes influencing the transition to circularity.

Table 11 Factors influencing the themes of the findings, (Source: Author,2024)

3.4.1. Economic Factors

Hotazel acts as an economic node within the JTM Municipality, (SDF, 2012). Nodes are ideally situated at primary access points within urban areas, usually where major mobility routes intersect major collector routes, Figure 26 below.

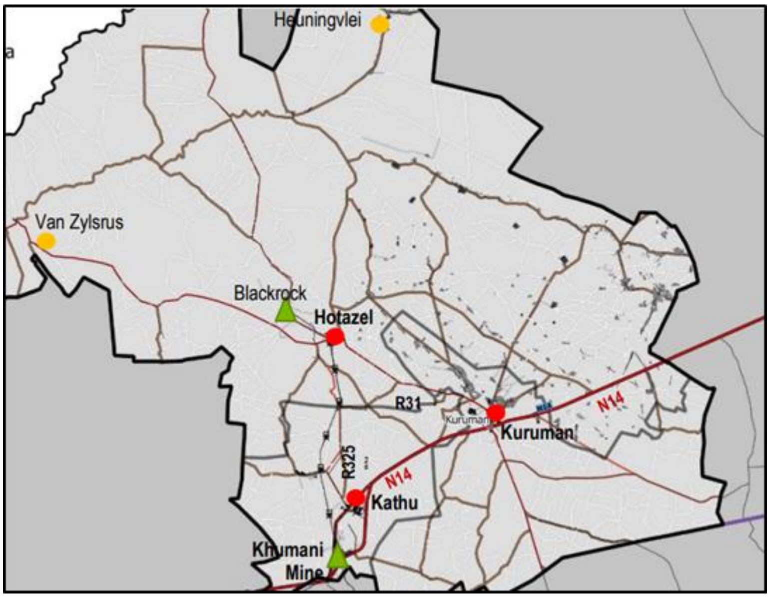


Figure 26 Relationship Triangle of Economic Nodes Closest to Hotazel, (Source: Basson,2018)

It is important to note the contribution mining of manganese has on the broader context of South Africa, beyond Hotazel. The chart below, Figure 27, shows the distribution of manganese mines in South Africa and shows that has 22 manganese mines, all of which are in the Northern Cape, except for 4 mines located outside Northern cape i.e. in Mpumalanga, Western Cape and North West.

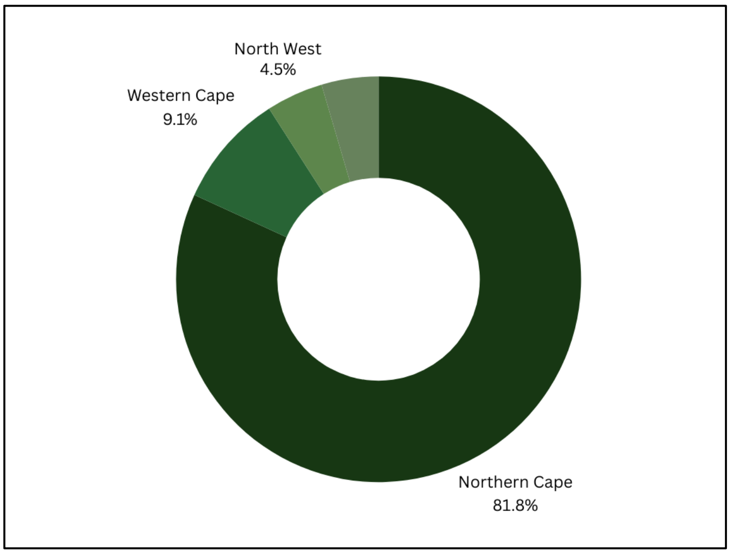


Figure 27 Pie Chart showing the distribution of Manganese Mines in South Africa, derived from Mining Weekly (Source: Author,2024)

This data is essential for assessing the influence of economic factors on resource efficiency in the residential built environment in South Africa. While the Northern Cape contributes to 81,8% of South Africa's manganese mines, the region also contributes to 80% of the world's manganese, (Creamer, 2020).

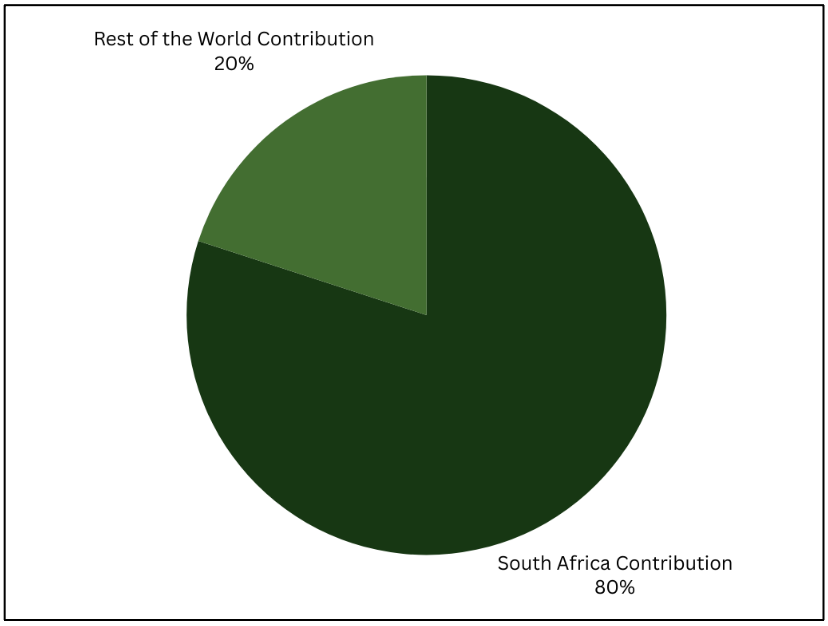


Figure 28 World Manganese Contribution, adapted from the Mining Weekly (Source: Author:2024)

When examining economic factors, it is essential to consider ownership. The companies owning mines in Hotazel are listed on the JSE, (Creamer, 2020). The chart below details the ownership of these companies. This information is essential for analysing capital resource availability in efforts to advance resource efficiency.

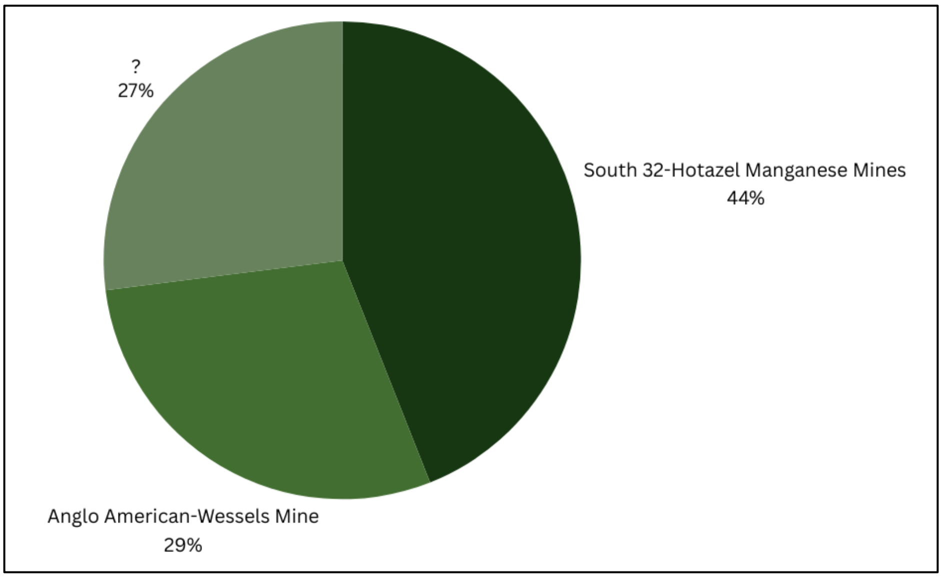


Figure 29 Mine Ownership percentages, adapted from Mining Weekly, (Source: Author,2024)

Similarly, noting the lifespan of mines, Figure 30, is crucial when identifying the economic factors influencing resource efficiency in the region, giving an understanding of the long-term economic planning and policy making of the town.

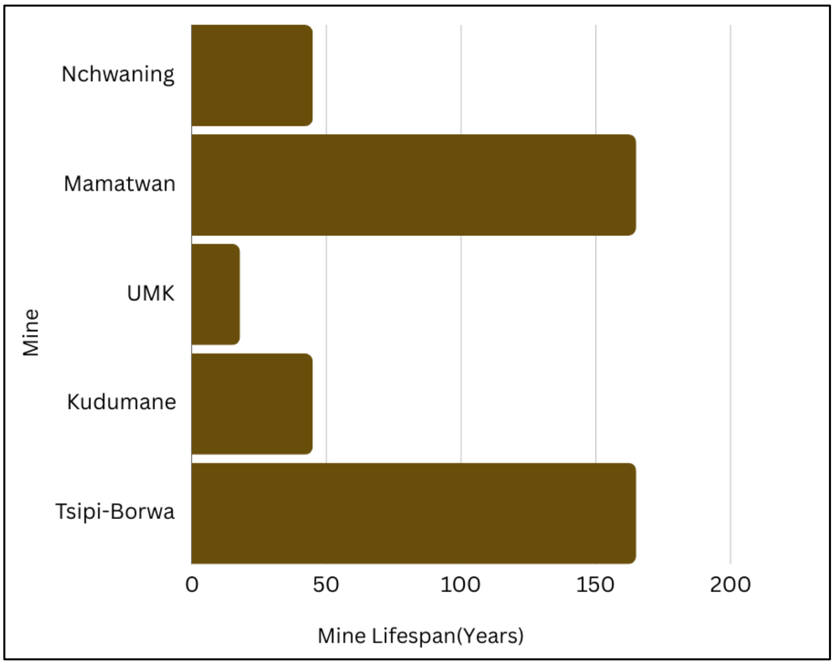


Figure 30 Lifespan of Mines in and around Hotazel adapted from the SDF, (Source: Author,2024)

As mentioned in the research background in chapter one, the municipality has 3 main economic sectors, being mining, agriculture, ecotourism, and community service, Table 2 Economic Indicators in the Region, (Source: Annelien Basson,2018).

Indicator	Gamagara Municipality	Joe Morolong Local Municipality
Main Economic Sectors	Mining, game farming and business services	Eco-tourism, agriculture, mining and community service

Table 2 Economic Indicators in the Region, (Source: Annelien Basson,2018)

The Sectors may be categorized into three, being primary sector, secondary sector and tertiary sector. Primary sector involves the direct utilization of natural resources, the secondary sector utilizes the output from the primary sector to manufacture finished goods while the tertiary sector encompasses activities within the soft economy, focusing on spaces where people impart knowledge and enhance productivity, potential, and performance.

As of 2012, the sectors contributed to the economy of the municipality as shown in the chart below, Figure 31,with the secondary sector growing at a rate of 7,1% per year deeming it the fastest growing sector and the tertiary sector growing at 2,3% per year (SDF, 2012).

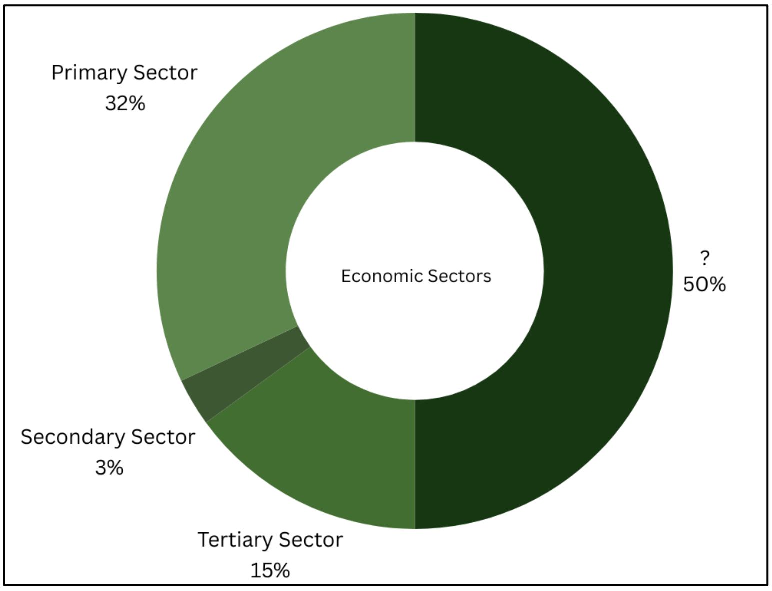


Figure 31 Contribution of each sector to the economy of the municipality, adapted from the SDF 2012, (Source: Author,2024)

This section has presented the findings concerning the economic factors of the town of Hotazel. The findings are essential in providing insights that facilitate a comprehensive analysis of the themes outlined. Understanding these economic factors is also essential in evaluating the current economic landscape of the town, identifying opportunities for growth and addressing challenges that may affect the transition from linear to circular.

3.4.2. Environmental Factors

Environmental management and assessment of environmental factors in the Northern Cape are a critical field to be studied when examining the transition from linearity to circularity. This section delves into framing the environmental landscape of Hotazel and the greater Northern Cape. Global challenges such as climate change and methods of energy used in the Northern Cape will be stated. Assessing the natural resources available and the impact of human activities on the environment is also imperative in the study of advancing resource efficiency. This section outlines the current environmental conditions faced in Hotazel, providing a baseline for developing circular strategies.

3.4.2.1. Waste Management

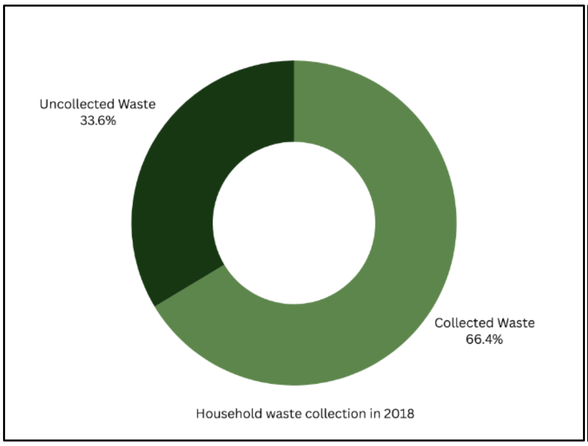
Managing waste in rural areas is a significant challenge for local governments in developing countries, (Viljoen, et al., 2021). Municipalities often have limited budgets and face difficulties in waste collection, compounded by inadequate equipment, infrastructure, and treatment facilities, (Viljoen, et al., 2021).

Curb-side waste management practices of households involve placing mixed household waste and recyclables at the curb for collection by the municipality or recycling company (Viljoen, et al., 2021).

Figure 32 Garden Waste Collection Point, Hotazel, (Source: Author,2024)

Figure 33 Household General Waste Collection point, Hotazel (Source: Author,2024)

Hotazel currently makes use of curb-side household waste management, Figure 32 and Figure 33. In South Africa, the percentage of households with waste collection services decreased from 66.4% in 2018 to 61.5% in 2019 Figure 34 and Figure 35.



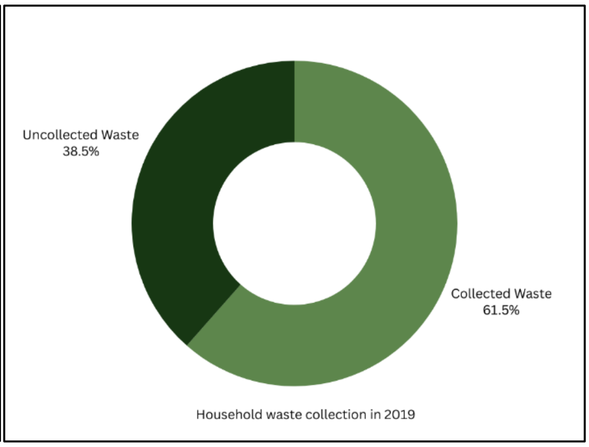


Figure 34 Household Waste Collection in 2018 adapted from Viljoen et al, (Source: Author,2024)

Figure 35 Household Waste Collection in 2019 adapted from Viljoen et al, (Source: Author,2024)

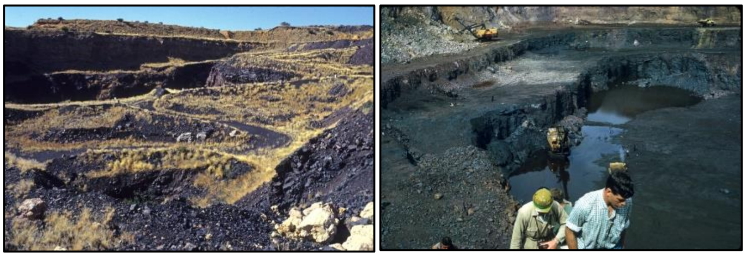
District and local municipality	Removed by local authority/private company/ community members at least once a week		Removed by local authority/private company/ community members less often than once a week		Communal refuse dump		Communal container/ central collection point		Own refuse dump		Dump or leave rubbish anywhere (no rubbish disposal)		Other		Total	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
DC45: John Taolo Gaetsewe	**17 373**	**24,0**	**464**	**0,6**	**3 465**	**4,8**	**1 045**	**1,4**	**45 925**	**63,5**	**2 623**	**3,6**	**1 414**	**2,0**	**72 310**	100,0
NC451: Joe Morolong	966	4,0	37	0,2	1 243	5,2	352	1,5	19 961	83,5	976	4,1	384	1,6	23 919	100,0
NC452: Ga-Segonyana	4 004	12,3	65	0,2	1 884	5,8	523	1,6	23 900	73,2	1 493	4,6	800	2,4	32 669	100,0
NC453: Gamagara	12 403	78,9	362	2,3	339	2,2	170	1,1	2 065	13,1	154	1,0	230	1,5	15 723	100,0

Figure 36 Statistics of Household waste removal in the district of Joe Morolong, (Source: Stats SA,2016)

Figure 36 shows that Joe Morolong, which is the local municipality within which Hotazel falls, has the lowest waste removal services in the region. The decrease in households with waste collection services in recent years underscores the ongoing difficulties faced in ensuring effective waste management systems across the region.

3.4.2.2. Mine dumps

Mine dumps, composed of crushed, sand-like by-product material called tailings generated during the mining process, contain a complex mixture of metals and dust particles (Nkosi, 2018). Communities living near mine dumps can experience high levels of dust exposure, especially during windy, dry conditions and when there is minimal vegetation cover (Nkosi, 2018). The town of Hotazel is surrounded by a couple of mine dumps. The closest mine dump to Hotazel is located on the south western side of the town, Figure 39. There are however six mine dumps in the vicinity of the town Figure 40.



Left and Middle: Figure 37 Hotazel Mine Dump, (Source: Mindat,2024)

Far right: Figure 38 Hotazel Mine Dumps, (Source: Author,2024)

Due to the increasing number of active mines and planned projects, efficient management of mine waste is crucial to mitigate environmental and community issues however the lack of a thorough mine waste database poses difficulties for waste management efforts (Koovarjee, et al., 2023).

Figure 39 Hotazel Mine dump, (Source: Google Maps,2024

Figure 40 Mine dumps in Hotazel, (Source: Google Earth Pro,2024)

In a study by (Nkosi, 2018) the impact of dust particles on communities residing near mine dumps was examined, revealing a notable prevalence of respiratory issues. The asthma rate specifically among children in these communities ranged from 10% to 13%, consistent with other South African studies. There is however a notable gap in research specifically addressing Hotazel, Northern Cape. Of the research articles on mine dumps in Hotazel, none of them address in depth, the issues posed by mine dumps.

3.4.2.3. Renewable energy

As of October 2023, 51 solar power stations are contributing clean energy to South Africa's grid (Labuschagne, 2023). Nearly 2,300 MW of South Africa's solar power is generated by PV plants, according to the IPP project database.

The Adams Solar PV2 solar park, a 75MW facility located in Hotazel, Northern Cape, Figure 41, produces 167 GWh of energy annually (Ndlovu, 2024) .The plant helps displace 171,700 metric tons of carbon dioxide each year and supplies energy to 100,000 households (Ndlovu, 2024).

Figure 41 Adams Solar PV2 Plant, (Source: Techcentral,2024)

The table below, Table 12 shows the solar farms available in the John Taolo Gaetsewe Municipality. Of the 3 nodes, Kathu, Kuruman and Hotazel, Kuruman is the only town without a solar farm while Kathu has the highest output of energy Table 12.

Name	Location	Province	Maximum Output
Adams Solar PV 2	Hotazel	Northern Cape	75MW
Kathu Solar Park	Kathu	Northern Cape	100MW
REISA	Kathu	Northern Cape	75MW
Sishen Solar Facility	Kathu	Northern Cape	74MW

Table 12 Solar farms in the John Taolo Gaetsewe Municipality, (Source: My broadband,2023)

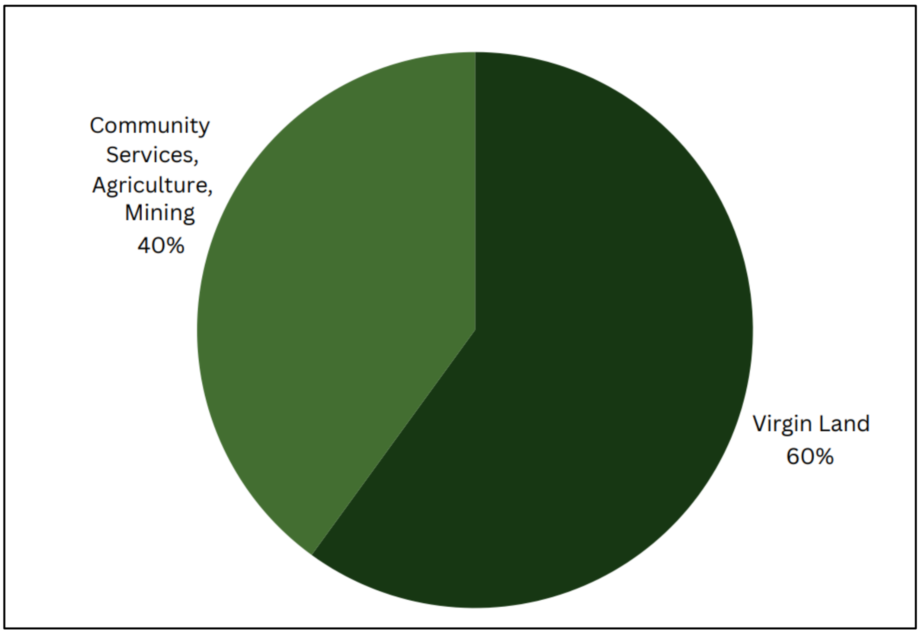


Figure 42 Composition of land and services provided in the municipality, (Source: Social Scoping Assessment,2020)

Nearly 60% of the Joe Morolong municipality consists of virgin land (Opperman, 2020). Examining the current renewable energy resources and methods in Hotazel is crucial for studying the transition to circularity and enhancing resource efficiency. Considering resources like virgin land offers valuable insights into potential opportunities for advancing resource efficiency in both the town and the broader region.

3.4.3. Infrastructural Factors

The region has an industrial character due to its mining activities, railway infrastructure, and electrical infrastructure, the adoption of increasingly intensive farming methods is shaping the perception of its agricultural character (Lubbe, 2021).In terms of housing, the region is predominantly a rural region and its industrial character is due to the activities listed above. This section outlines the services and infrastructure found in the region of Joe Morolong local municipality.

Table 13 summarizes the following services in the municipality of Joe Morolong:

- 84% of households in the municipality have access to electricity for lighting.
- 5.4% of the households have access to flush toilet connected to sewerage.
- 4,8% of the households have access to piped water.
- 4% of the households have access to weekly refuse removal.

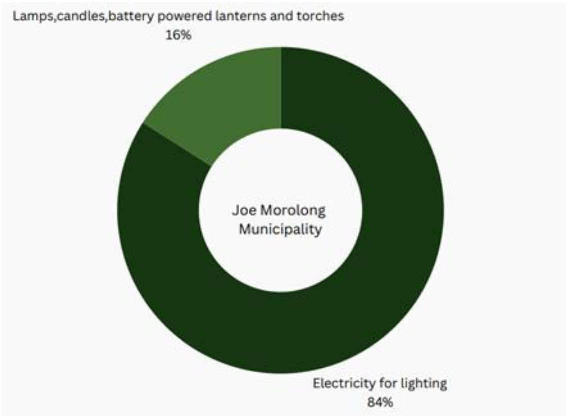
<table>
<tr><th colspan="2">Summary of services available in Joe Morolong Local Municipality</th></tr>
<tr><td>

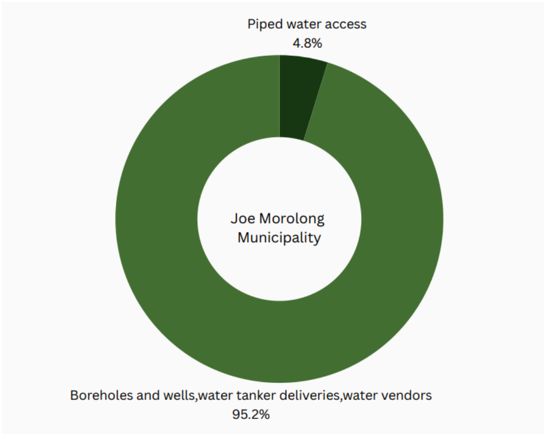
Figure 43 Access to electricity lighting, (Source: Opperman,2020)</td>
<td>

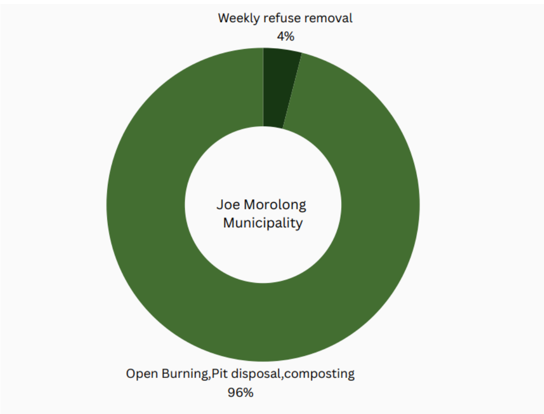
Figure 44 Piped water access, (Source: Opperman,2020)</td></tr>
<tr><td>

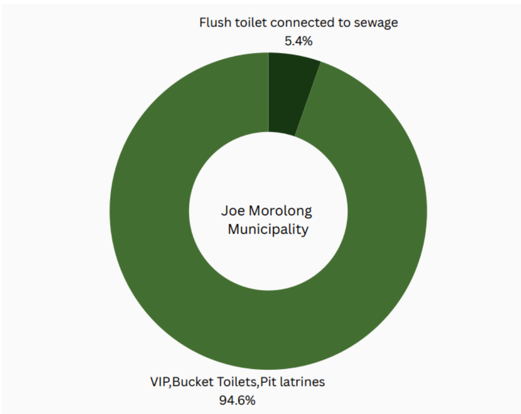
Figure 45 Refuse removal, (Source: Opperman,2020)</td>
<td>

Figure 46 Flush toilet, (Source: Opperman,2020)</td></tr>
</table>

Table 13 Summary of services of the Joe Morolong Municipality, (Source: Author:2024)

The summary of services in the Joe Morolong municipality show low percentages of access to basic amenities. (Petrie, et al., 2022) state that though Hotazel is one of the nodes in the region, the following issues were noted:

- Residents face significant challenges in accessing water and electricity.
- The roads are in a bad state.
- Communities have not experienced any advantages from the emergence of new solar companies in the region.

3.4.3.1. Transport networks

People, goods, and services flow along designated routes, forming a network of interaction. Intersections in these networks create activity nodes where interactions occur. The level of interaction determines the size and hierarchy of these nodes. Surfaces connect these nodes and networks, forming a cohesive system, Figure 47.

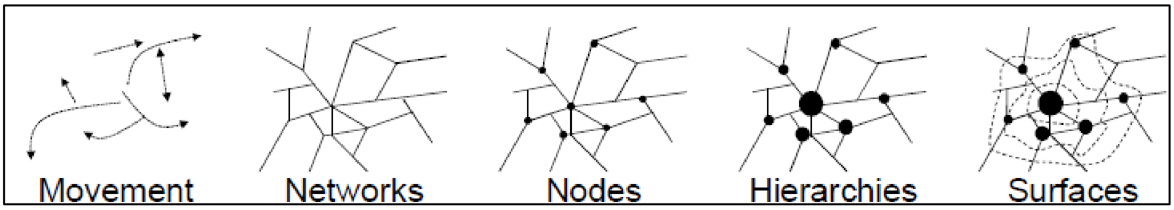


Figure 47 Network of interactions between regions, (Source:SDF,2012)

The municipality has inadequate road networks, resulting in low movement levels across most areas. There are also limited transport options, low volumes of transportation, and restricted mobility for households within the region pose challenges for the implementation of resource efficiency in the town (SDF, 2012).

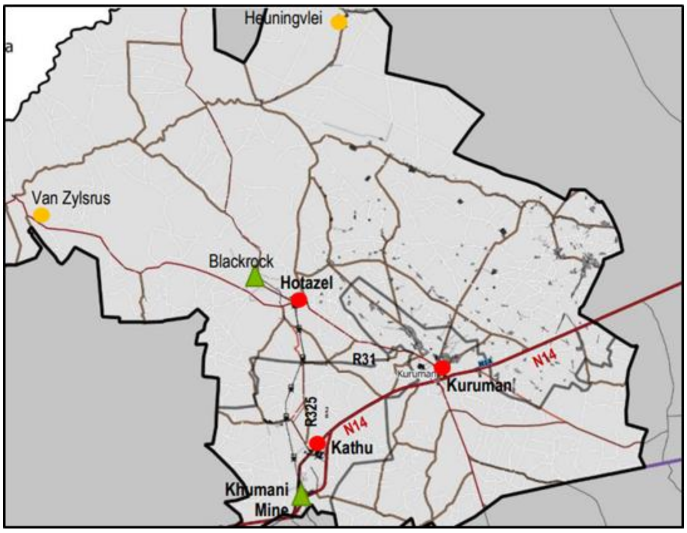


Figure 48 Network of roads (Source: Basson,2018)

- Figure 48 depicts the local roads within the municipality including R31 and R325.
- The road infrastructure are in a good and functional condition (see Figure **49** and Figure **50**).
- The town also possesses operational railway infrastructure for the transportation of raw materials and goods (see Figure **51** and Figure 52).
- The town features a functional airstrip accessible from R380 for flight operations (see Figure 53 and Figure 54).

Table 14 summarizes the transport infrastructure available in the town and within the local municipality.

Transport Infrastructure	
 Figure 49 R31 route from Kuruman to Hotazel, (Source: Author,2024**)**	 Figure 50 R31 route, (Source: Author,2024)
 Figure 51 Railway infrastructure, (Source: Author,2024)	 Figure 52 Railway infrastructure, (Source: Author,2024)
 Figure 53 Hotazel Airstrip, (Source: Maps,2024)	 Figure 54 Hotazel Airstrip accessed from R380, (Source: Google Earth Pro,2024)

Table 14 Images of the transport infrastructure in Hotazel, (Source: Author,2024)

Transport infrastructure plays a vital role in enabling the transition from linearity to circularity by giving insight on gaps to optimize resource use, waste, and allowing sustainable development in the environment. It is imperative to have an insight on the available infrastructure.

3.4.4. Expertise and skills

While the mining sector plays a pivotal role in the economy of Hotazel and the greater province, it is imperative to note other sectors and industries available in the region. It is important to shed light onto the qualification levels generally within the broader context of the municipality which then provides a picture of what skills can be extracted from the region in order to be able to advance resource efficiency in the region. In the context of the municipalities of Joe Morolong, Ga-Segonyana and Gamagara municipality, there is a limited availability of lack of skill. The figure below shows the levels of education that are available in the overall context of the John Taolo Gaetsewe District Municipality.

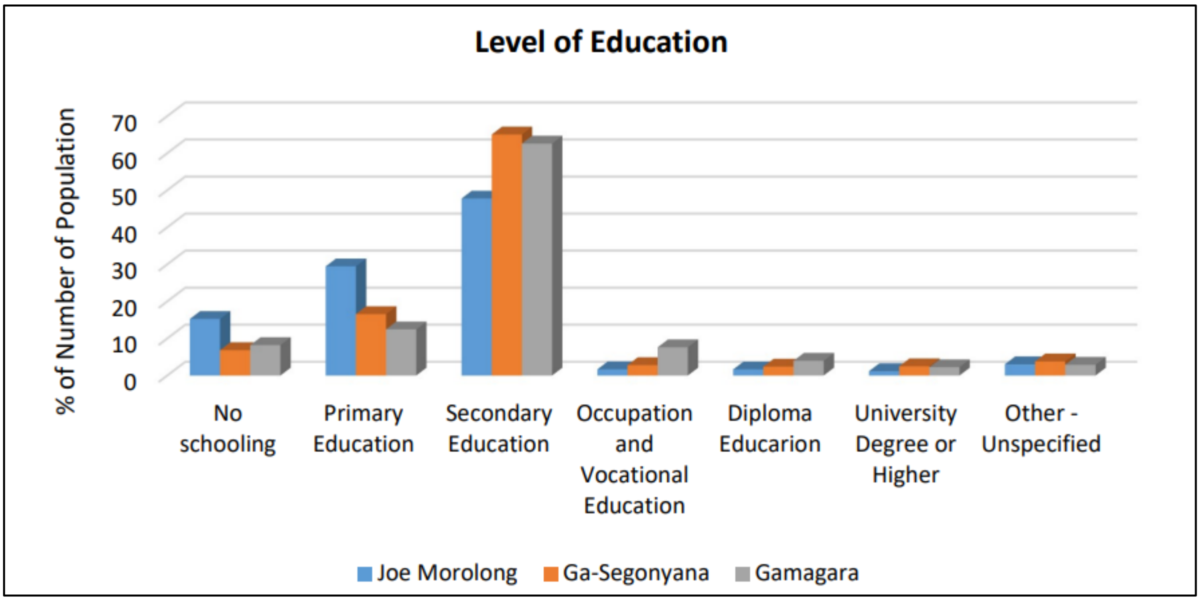


Figure 55 Levels of Education for the population aged 20years and Older within the JTGDM, (Source: JTGM,2020)

As shown in the figure above, education attainment levels are relatively low. A significant portion of the population have not attended any form of schooling and a very small percentage have achieved any post-matric qualifications.

In the earlier sections of this thesis in the literature review, (Mhlanga, et al., 2022) highlights the significant role of significant role of stakeholders particularly professionals in the construction industry in driving the shift from linear to circular models. It is also highlighted; how imperative community engagement is in the transition however the findings specific to Hotazel indicate a notable lack of necessary skills to enhance the transition.

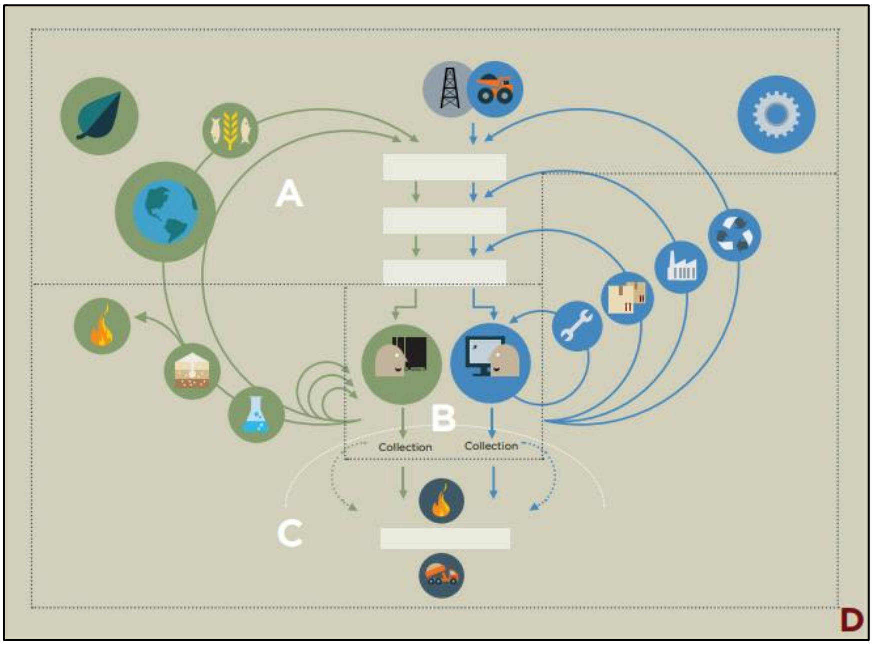


Figure 56 Blocks to enhance a circular economy, (Source: Ellen MacArthur Foundation,2013)

In (Ellen MacArthur Foundation, 2013), Figure 56,the steps A, B, C and D are required to achieve a circular economy.

A- Skills related to designing and producing circular products.

B- Innovative models for conducting business.

C- Expertise in constructing cascades

D- Factors that facilitate enhanced performance across cycles and sectors

To achieve step D, the following steps have been found to be mandatory, according to (Ellen MacArthur Foundation, 2013):

1. Factors that promote collaboration across different cycles and sector.
2. Conducive investment environment.
3. Education: Increased awareness among the general public and business community and incorporating circular concepts into university curricula.

In contrast to the information mentioned above, Hotazel, with its population of fewer than 1500 residents, as depicted in Figure 57, indicates that 45% of individuals possess high school qualifications as their highest level of education attained.

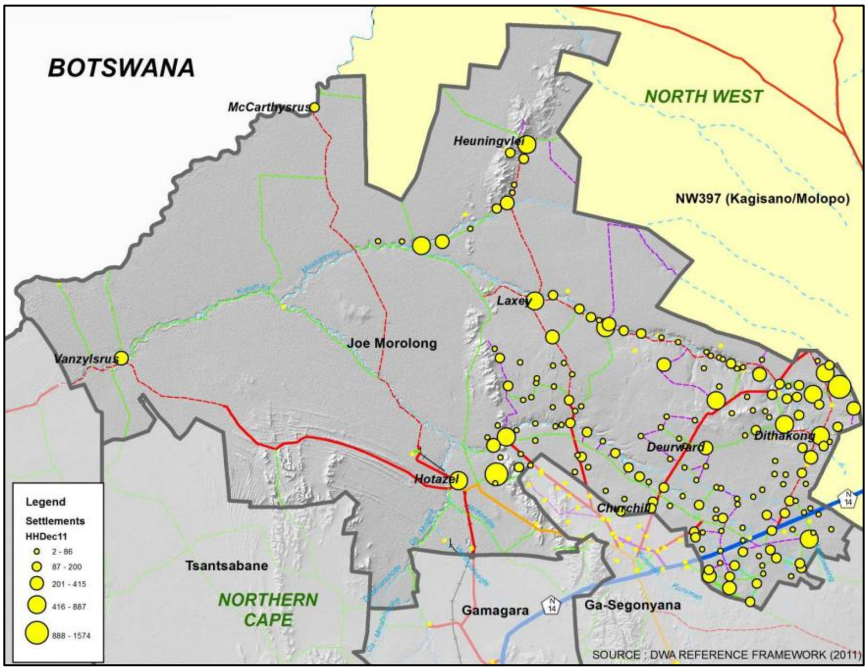


Figure 57 Population numbers of the JTGDM, (Source:SDF,2012)

In conclusion, the region faces significant deficits in educational attainment and skills necessary for advancing resource efficiency as discussed in earlier chapters. The data reveals that a substantial portion of the population lacks formal education.

3.4.5. Architectural Typology

In the Joe Morolong LM, there are 23,919 households, with 80.1% consisting of formal dwellings (Opperman, 2020). A significant 67.99% of households live in houses or brick structures on separate stands (JTGDM, 2021). Local residents report that Hotazel has 950 houses, with only three being privately owned, the remaining homes are maintained by the Australian mining company South32 (O'Regan & Davis, 2024) . The town predominantly has made use of traditional construction techniques. This trend reflects the broader housing patterns within the district. In Hotazel, this pattern is even more pronounced, with 100% of the houses being constructed from brick and mortar and 100% of the households being formal households inclusive of public spaces and commercial space see Table 15.

Typical architectural typology	
 Figure 58 Typical household type (Source: Author,2024)	 Figure 59 Hotazel CCTV headquarters (Source: Author,2024)
 Figure 60 Hotazel library, (Source: Author,2024)	 Figure 61 Hotazel wellness centre, (Source: Author, 2024)

Table 15 Images of the typical architectural typology in Hotazel, (Source: Author,2024)

The Joe Morolong LM has a more dispersed human settlement pattern, spread across approximately 154 villages and three small towns, (JTGDM, 2021). Hotazel however has a more clustered settlement pattern Figure 62.

Figure 62 Hotazel settlement pattern, (Source: Author,2024)

Studying the architectural typology in Hotazel helps gain an insight on local needs, cultural preferences and availability of resources. This supports the broader goal of advancing resource efficiency in remote and arid regions by allowing for the creation of sustainable, culturally relevant, and resource-efficient.

3.4.6. Policy, Regulatory and Building Codes

Construction waste in South Africa, makes up approximately 20% of all solid waste, but only around 16% of it gets recycled (Department of Environmental Affairs, 2012). The building types and construction practices reveal opportunities to minimize construction waste and boost recycling through proactive design processes, regulations and standards, capacity development, and local support systems (Gibberd, 2020). Policies and regulations for building and construction differ significantly across Africa. The implementation of policies and regulations are not strong due to incapacitation within government and the built environment professional and industry sectors (Gibberd, 2020) however the Industrial Policy Action Plan (IPAP) developed by the government of South Africa, is a policy that advocates for the use of domestically produced materials and products over imported ones. The department of public works in 2018 launched the Green Building Policy which aims to be the industry leader in sustainable construction by emphasising efficient waste, water, and energy management; enhancing indoor environmental quality and comfort; and encouraging sustainable product and material management (NDP, 2018).The following policies are currently in place:

Policy	Description
i. National Environmental Management Act (No. 107 of 1998) (NEMA)	NEMA functions based on the Bill of Rights, which states that every individual has the right to an environment that does not endanger their health or well-being.
ii. White Paper on the Renewable Energy Policy of the Republic of South Africa (2003)	The policy acknowledges the possibilities of renewable energy and seeks to establish the prerequisites for the advancement and commercial application of renewable energy technology.
iii. National Development Plan 2030 (2012)	Aims for the development and expansion of the economy through sufficient investment in the energy infrastructure.
iv. Strategic Infrastructure Projects (SIPs)	The five primary purposes are to widen opportunities, change the economic environment, generate new employment opportunities, improve the provision of essential services, and aid in the integration of African economies.
v. Northern Cape Provincial Spatial Development Framework (PSDF)	Five primary purposes are to widen opportunities, change the economic environment, generate new employment opportunities, improve the provision of essential services

Table 16 Policies affecting the transition to circular spatial economies, (Source: Opperman,2020)

3.4.7. Conclusion

The findings have provided an understanding of the factors affecting the transition from linearity to circularity in Hotazel's residential built environment. Economic factors reveal barriers such as high costs and limited financial incentives, which affect the adoption of circular practices. Environmental impacts highlight the urgency of integrating circular approaches due to the town's ecological vulnerabilities. Infrastructural constraints, including inadequate technological infrastructure, limit the implementation of innovative circular solutions. The lack of skilled expertise further exacerbates the shift towards circular construction methods and use of improved technology. Architectural typologies reflect current design preferences and current trends. The outdated policies and building codes act as significant barriers, revealing the need for regulatory reform to support circularity initiatives. Together, these findings outline the complex landscape that shapes Hotazel's transition to a circular economy and provide insights that align with the study's research questions, emphasizing the need for targeted interventions in policy, technology, and skills development.

4. Analysis

The purpose of this study is to explore the transition from linear to circular economies in the residential built environment, specifically focusing on arid and remote regions, using Hotazel as a case study. This research aims to address the overarching question and sub questions.

Overarching Question: How can the residential built environment in arid and remote locations effectively transition from linear to circular spatial economies?

Sub-Question 1: What are the principles of circularity that can effectively guide the transition of the residential built environment in its remoteness and aridity?

Sub-Question 2: What alternative construction systems align with principles of circularity?

Sub-Question 3: In what ways can resource efficiency initiatives be integrated into the built environment to promote circularity in arid and remote areas?

Using the questions above, this section covers the analysis of the findings in section 3.4.The findings of the study have been categorized and presented into distinct themes,(see Table 17) as done in the findings chapter, 3.4.

Factors	Count	Description
4.1.1 Economic Factors	Financial impacts	Analysing the stated barriers and incentives related to circular construction practices in the study area.
4.2.2 Environmental Impact	Ecological impacts	Analysis of the current nature of the environment of the town.
4.3.3 Infrastructural Factors	Physical and logistical impacts	Analysis of the factors that affect the adoption of circular construction principles.
4.3.4 Expertise and skills	Qualifications	Analysis of the availability of skills enough for the implementation of circular construction
4.3.5 Architectural Typology	Preferences and dominant typologies	Analysis of the design and structural characteristics of the town.
4.3.6 Policy, Regulatory and Building Codes	Current policies	Analysis of the existing regulations and building codes influencing the transition to circularity.

Table 17 Factors influencing the analysis of the themes from the findings, (Source: Author,2024)

The following tables , Table 18 to Table 21below analyses the findings using the method highlighted in Table 17.

Summary of theme	Analysis of finding
4.1.1. Economic factors	
In this table, the analysis of the economic factors in Hotazel, taking into account, the sectors available in the town, the impact of mining, agriculture and tourism. Outlining these factors and their impact are essential in assessing the town and the region's readiness to transition from linearity to circularity.	
i. Economic contribution & ownership	• The companies with ownership of majority of the infrastructure in the town of Hotazel and operating in the mines are predominantly listed in the Johannesburg Stock Exchange (JSE) this indicates a substantial amount of capital resources that could be used to influence the transition for current and future projects in the town of Hotazel.
ii. Contributions by sector • Primary Sector • Secondary Sector • Tertiary Sector	• There is a direct utilization of natural resources such as mining activities that primarily make use of manganese which is abundant in the region. • Mining of the manganese leads to the effect of mine dumps. • Mine dumps can be exploited for further use and further resource extraction. • The utilization of primary sector resources like that of mine dumps for manufacturing finished good can enhance circular principles in the region as the anchoring point for circularity is the minimization of waste production.
Sub Question 1	
• The principles of circularity advocate for minimizing waste, maintaining product value through reuse, and regenerating natural systems. In Hotazel however there is a dominant linear approach which is the extraction of manganese. The lack of literature data on the recycling and reuse of materials suggests challenges in aligning with circular principles.	
Sub Question 2	
• There is a need for economic diversification and policy incentives to promote circular construction methods in order to mitigate resource depletion and environmental impact.	
Sub Question 3	
• Resource efficiency initiatives in Hotazel can take advantage of the economic strengths, particularly in mining, to fund sustainable practices. However, the current economic structure's reliance on primary sector activities limits initiatives for comprehensive resource efficiency.	

Table 18 Analysis of findings for the economic factors (Source: Author,2024)

<table>
<tr><th colspan="2">4.1.2. Environmental factors</th></tr>
<tr><td colspan="2">In this table, the analysis of the environmental factors in Hotazel, taking into account, the waste management practices, the impact of mine dumps and renewable energy initiatives is conducted. Outlining these factors and their impact are essential in assessing the town and the region’s readiness to transition from linearity to circularity.</td></tr>
<tr><td>i. Waste management</td><td>• Managing waste in remote areas like Hotazel poses difficult challenges. The remoteness of the town does not make the collection of waste an easy task.
• The municipality of Joe Morolong which is the municipality within which Hotazel is located, faces challenges in waste collection due to inadequate equipment and infrastructure, as well as treatment facilities, (Viljoen, et al., 2021).This hurdle is however not unique to the region but is a national crisis as the percentage of household waste collection services in South Africa faced a decline from 66.4% to 61.5%, (Viljoen, et al., 2021).
• This heightens the need to transition to circular practices so as to reduce the burden on the municipality to collect waste by incorporating measures that reduce waste production in households.</td></tr>
<tr><td>ii. Mine dumps</td><td>• The increasing number of mining activity increases the need to practice efficient mine waste management.
• Currently, there is a lack of comprehensive mine waste literature data that outlines the plans to deal with mine dumps.
• The lack of mine waste literature data in South Africa, complicates the study of waste management efforts.</td></tr>
<tr><td>iii. Renewable energy</td><td>• The town shows a positive step towards circular energy use practices.
• The Adams Solar park displaces 171 000 metric tones of carbon dioxide each year, (Nkosi, 2018),this contributes significantly to the clean energy grid of South Africa.
• This literature data shows that there is a positive step towards transitioning to resource efficiency and circular practices. With the availability of land, i.e. 60% of virgin land (Opperman, 2020) that can be used for the implementation of more renewable energy plants like the solar park in Hotazel.</td></tr>
<tr><td colspan="2">Sub Question 1</td></tr>
<tr><td colspan="2">• The current waste management practices in Hotazel reflect a linear approach, with limited infrastructure and declining service coverage.
• The challenges faced in waste collection show the need for improved systems that align with circular economy principles.
• Mine dumps indicate a linear extraction process with great waste generation. Circular principles seek to enhance better management of mine tailings, like reprocessing and repurposing materials to reduce environmental harm and resource depletion.</td></tr>
<tr><td colspan="2">Sub Question 2</td></tr>
<tr><td colspan="2">• Alternative construction systems that incorporate recycled materials and promote waste reduction could address the inefficiencies in current waste management practices.
• Making use of alternative practices like that of design for reuse mentioned in resource efficiency chapter 0.</td></tr>
<tr><td colspan="2">Sub Question 3</td></tr>
<tr><td colspan="2">• Implementing recycling programs, waste-to-energy technologies, and community education initiatives can reduce waste and improve resource utilization as mentioned in design for energy efficiency, 0.</td></tr>
</table>

Table 19 Analysis of findings for the environmental factors (Source: Author,2024)

4.1.3. Infrastructural factors	
This section analyses the transport networks in Hotazel. Analysing transport networks gives insight to the role they play in advancing resource efficiency in remote regions.	
i. Road Networks	The current road infrastructure is adequate for the advancement of resources and transportation of raw materials, however studies state that road infrastructure is inadequate, (SDF, 2012).
ii. Railway Infrastructure	The presence of railway infrastructure offers potential for sustainable transportation of goods, reducing the reliance on road transportation which minimizes carbon emissions, therefore advancing resource efficiency.
iii. Airstrip	The airstrip enhances connectivity and facilitates ease of transportation of movement of goods and people which can support resource efficiency. Air transport in remote regions however, tends to be costly.
Analysing the transport networks in Hotazel in relation to the research questions insights for advancing resource efficiency and transitioning to a circular economy. Addressing the inadequacies in road networks, optimizing the use of railway infrastructure, and exploring the potential of the airstrip are essential strategies. These efforts can enhance connectivity, reduce environmental impact, and support circular development in Hotazel's built environment. This analysis provides a foundation for developing targeted strategies to address transport-related challenges and meet opportunities for circularity in Hotazel.	

Table 20 Analysis of findings for the infrastructural factors (Source: Author,2024)

4.1.4. Expertise and skills	
This section analyses the skills available in Hotazel. The focus is on the education attainment levels and their impact on advancing resource efficiency. In the literature review, it is highlighted how there is a lack of skill when it comes to circularity. Analysing the skills available gives insight on how the town can advance skills in order to transition from linearity to circularity.	
Education levels	The region has low education levels with a small percentage of the population having achieved post-matric qualifications, (JTGDM, 2021).There is a limited availability of skills necessary to drive the transition to a circular economy.
Sub Question 1 • Building a knowledgeable workforce that can innovate circular economy practices is essential. Promoting education in circular economy concepts is crucial for the transition. As outlined in the literature review, there is few literatures that covers circularity in Africa however it is necessary for the successful implementation of circularity, (Amarasinghe, et al., 2024). • (Antwi-Afari, et al., 2021) highlight a lack of collaboration amongst stakeholders, this is also evident in Hotazel, encouraging collaboration between educational institutions, industries, and communities to create skill development programs tailored to the needs of the region is essential.	
Sub Question 2	
• Low levels of skilled labour inhibit the adoption of advanced alternative construction systems. • This results in foreign labour being employed due to the lack of skill in Hotazel. This then makes it difficult for the community of Hotazel to be self-sufficient, which is one of the anchoring points of circularity and advancing resource efficiency.	
Sub Question 3	
• Low educational levels in Hotazel make it difficult to adopt resource efficient practices, resulting in the reliance on foreign skill.	

Table 21 Analysis of findings for the expertise and skills factors (Source: Author,2024)

4.1.5. Architectural typology
This section analyses the architectural typology in Hotazel, focusing on the types of dwellings, construction techniques, and settlement patterns. It examines how these factors influence the transition from linear to circular economies, particularly in the context of advancing resource efficiency in arid and remote regions.
• The dominant use of traditional brick and mortar construction in Hotazel reflects a linear approach to building. • The clustered settlement pattern in Hotazel offers potential for implementing circular practices more effectively compared to dispersed settlements. This allows for centralized resource management and infrastructure development, facilitating the transition to circular practices.
Sub Question 1
• The reliance on traditional brick and mortar construction limits the flexibility for adopting circular building practices, incorporating sustainable construction materials, such as recycled or locally sourced materials as mentioned in 02.3.2 literature review, can reduce the environmental impact and align with circular economy principles.
Sub Question 2
• Making use of modular and prefabricated construction techniques can also enhance resource efficiency and adaptability as stated in the literature review,0 2.3.2. • Exploring alternative construction systems, such as earth-based construction, 0, may offer sustainable and culturally relevant solutions in the region.
Sub Question 3
• Making use of passive design strategies, such as natural ventilation and insulation, can reduce energy consumption. • The clustered settlement pattern allows for centralized systems for water management, waste recycling, and renewable energy generation can enhance resource efficiency.

Table 22 Analysis of findings for the architectural typology factors (Source: Author,2024)

4.1.6. Policy, regulations and building codes
Sub Question 1
The NEMA Act, promotes sustainable development and health, which are essential to the circular economy's goals of reducing waste and conserving resources.
Sub Question 2
The White Paper on renewable energy promotes the use of renewable resources and the reduction of environmental effect.
Sub Question 3
The National Development Plan emphasises the development and investment in infrastructure, which can improve resource efficiency in building and urban planning.

Table 23 Analysis of findings for the policy, regulations and building codes factors (Source: Author,2024)

5. Discussion

This section will cover the impacts and implications of the findings of the study. While Hotazel offers potential for transitioning from linearity to circularity, advancing resource efficiency, several challenges have been noted in the findings section,3.4 and analysed in section 4. There are factors that act as a barrier to attaining resource efficiency in the town while some factors offer opportunities for implementation of circular principles in the built environment. As highlighted in the study, these include:

- Economic factors
- Environmental factors
- Infrastructural factors
- Expertise and skills
- Architectural typology
- Policy, regulations and building codes

In order to be able to answer the overarching question: '*How can the residential built environment in arid and remote locations effectively transition from linear to circular spatial economies?*' it is important to recap and outline the definitive factors of a circular economy, see 5.1.

5.1. The circular economy

The circular economy may be defined as a substitute for the conventional and traditional linear economy where the resources are utilized for as long as possible, with the goal to maximize their value during use, then recovering and regenerating some products and materials at the end of their life cycle (Castro & Pasanen, 2019).When looking at the building as a unit, Frank Duffy described a building as layers of longevity consisting of built components, (Castro & Pasanen, 2019). Brand then expanded this concept which encompasses structure, space planning, site, stuff, services and the skin of buildings, Figure 63.

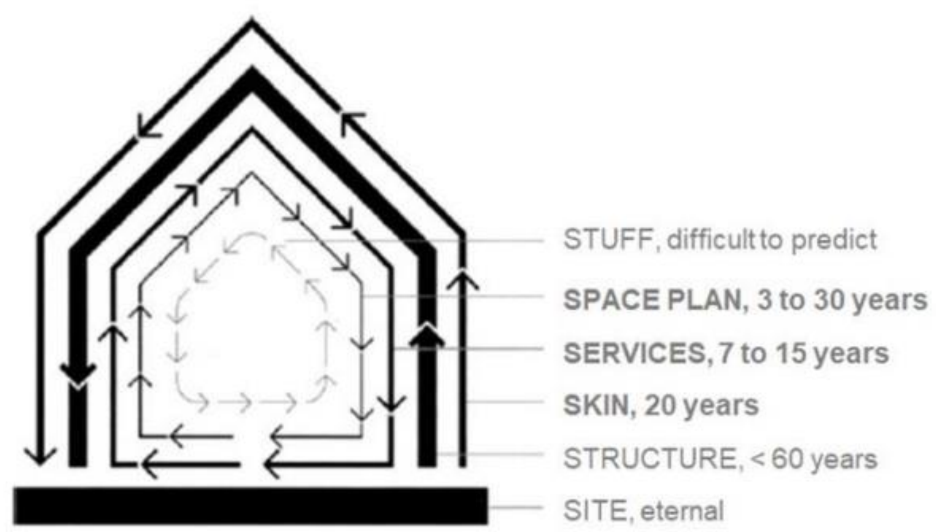


Figure 63 Rates of change in building components, (Source Castro et al,2019)

Figure 63 illustrates how each layer has a life span based on material, technology and user preferences. To steer the building design process effectively, it is crucial to assess the impacts of available options to implement these measures (Castro & Pasanen, 2019). The following section covers the drivers, barriers and strategies to implementing circularity in Hotazel, see 5.2.

5.2. The circular economy in Hotazel

The findings and analysis of the study, cover factors that influence the resources available to drive resource efficiency in the built environment in Hotazel. It is imperative to acquire data for timely analysis and for quantifying improvement, however in the case of Hotazel, findings show a major gap in the necessary measures required to drive the shift to circularity. In this section, a discussion on the drivers, barriers and strategies is carried out using the findings and analysis from the literature data in preceding sections. The key enablers for the development and implementation of effective waste prevention policies i.e. advancing resource efficiency, action plans, and initiatives are unpacked in Table 24

Drivers	Barriers	Strategies
Economic Factors		
• The presence of mining as a major sector highlights the presence of high investment potential which can effectively drive the development of the built environment in Hotazel.	• A lack of diverse skills in the workforce hinders the development of new economic sectors like that of enhancing circularity in the town.	Encourage investment in industries that create alternative building methods and materials.
Environmental Remediation		
• The high solar irradiance in Hotazel makes it an ideal location for solar power generation, supporting renewable energy initiatives. • The large areas of virgin land provide an opportunity to implement renewable energy practices. • The global focus on climate change and sustainability drives local efforts to adopt environmentally friendly practices.	• The affordability of landfilling presents a significant challenge as it promotes waste generation, given its current convenience and low cost. • Insufficient data on waste streams. • The presence of mine dumps contributes to dust pollution. • Insufficient waste management infrastructure due to the remoteness of the town. • The aridity of the town limits water availability.	• Careful management of mining impacts • Strengthen environmental regulations and compliance standards with regards to mine dumps. • Implement climate resilient infrastructure. • Raise awareness and empower communities on the importance of circularity.
Infrastructural Interventions		
Existing road and rail infrastructure supports the transportation of goods and services, enhancing economic activities.	• There is a need for innovative construction methods as highlighted by the major incline towards brick and mortar construction techniques in Hotazel.	• Build and waste management facilities to improve collection, recycling, and disposal services.
Expertise and skills		
• Institutional frameworks capable of evolving decision-making processes through enhanced collaboration and consultations with key stakeholders in government, the private sector, research institutions, and civil society, underpinned by scientifically rigorous data and methodologies.	• Low education attainment levels. • There is a misconception among communities that products containing recycled or reused content are of lower quality than those manufactured from virgin materials.	• Curb the lack of awareness of the concept of circularity. • Effective distribution of new and evolving information to both public and private sectors is essential to highlight the advantages of circular measures.
Architectural typology		
• There is dominant use of brick and mortar construction methods, which shows the need	• The dominant use of traditional brick and mortar construction methods limits the adoption of more circular practices and	• Implement educational campaigns to raise

to enhance other typologies in the town.	resource-efficient building techniques.	awareness on the benefits of circular building techniques. • Provide training programs for local builders and contractors on innovative construction techniques and materials.
Policy, regulations and building codes		
• Initiatives to facilitate public and private investment where producers assume physical and/or financial responsibility for products after their use to prevent disposal.	• Absence of specific building codes and regulations tailored to the unique environmental and socio-economic conditions of Hotazel can hinder the implementation of circular spatial economic practices.	• Incentives aimed at fostering behavioural change, particularly by internalizing the social and environmental impacts of waste production, are crucial to ensure that producers and consumers take responsibility for waste prevention thus adopting circular principles and advancing resource efficiency in the built environment.

Table 24 Drivers, barriers and strategies in advancing resource efficiency in Hotazel, (Source: Author:2024)

5.3. Implications

The findings highlight critical barriers and opportunities specific to Hotazel, providing insights into effectively transitioning its residential built environment from a linear to a circular economy. These reveal the necessary steps, such as tailored policies, stakeholder collaboration, and utilizing local resources, to effectively transition Hotazel's built environment. Local challenges like educational gaps and reliance on traditional construction methods hinder transition efforts, while community engagement and resource availability present opportunities for sustainable development. Architecture can learn to integrate local materials, improve waste management practices, and prioritize community engagement to enhance sustainability and resource efficiency in remote and arid regions like Hotazel.

6. Conclusion

This study set out to explore how the built environment in remote and arid regions, specifically Hotazel, can transition from linear to circular economies, with an emphasis on resource efficiency. Addressing the overarching question of how this transition can be effectively realized, the study identified key barriers and enablers that influence the process, drawing from existing literature and contextual analysis.

6.1. Addressing research questions

6.1.1. Principles of Circularity

The study identified core circularity principles relevant to Hotazel, including adaptability, modularity, and the prioritization of locally sourced, renewable materials. These principles are crucial in arid and remote contexts where resources are limited and environmental conditions are harsh. The research emphasized the need to adopt circular design approaches that support resilience, minimize waste, and enhance resource regeneration. While these principles are highlighted, the application of these concepts remains limited in the current built environment, reflecting the need for more targeted research and pilot projects in similar contexts.

6.1.2. Alternative Construction Systems

Through the literature review, alternative construction systems such as modular and prefabricated designs were identified as effective methods that align with circularity principles. These systems not only reduce material waste but also offer flexibility and adaptability, crucial in environments like

Hotazel. The study emphasized that to adopt these systems, significant shifts in local practices, skills development, and investment in technology are necessary. The findings call for further exploration of how these construction methods can be tailored to suit local conditions, considering factors such as material availability, cultural acceptability, and economic feasibility.

6.1.3. Resource Efficiency Initiatives

Resource efficiency initiatives, such as material circularity, were analyzed for their potential to support circularity in arid regions. The study however highlighted that the current infrastructural and regulatory environment in Hotazel is not conducive to such initiatives, often due to outdated building codes and lack of supportive policies. The literature indicates that improving regulatory frameworks and increasing stakeholder collaboration are critical steps toward integrating resource efficiency into the built environment,reflecting the need for an approach that involves policy reforms, financial incentives, and public awareness to drive the transition.

6.2. Reflection on the literature

The study's reliance on secondary literature revealed significant gaps in knowledge, particularly concerning African and remote contexts. The review of existing research highlighted that most literature on circularity is Eurocentric, with limited relevance to Hotazel's unique environmental and socio-economic conditions. This disconnect points to the critical need for more context-specific studies that address local challenges and opportunities. While the literature broadly covers circularity concepts, there is a lack of critical engagement with how these can be practically implemented in arid, remote regions like Hotazel. The findings suggest that much of the existing work does not adequately address the complexities of transitioning to circular economies in such settings, leaving an open space for more in-depth, localized analysis and experimentation.

6.2.1. Way forward

The study concludes that transitioning from linear to circular spatial economies in Hotazel requires a multifaceted approach that combines innovative construction methods, policy reform, stakeholder engagement, and education. The study acknowledges that the lack of field data limits the depth of these findings. Future research should prioritize empirical studies, pilot projects, and direct engagement with local stakeholders to validate and refine the proposed strategies. By addressing these gaps, the study lays the groundwork for a more targeted and effective approach to advancing circularity in remote and arid environments, contributing valuable insights to the broader discourse on sustainable development in these challenging contexts.

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