Development of a framework for assessing smart city readiness in South African municipalities: A case study of Matjhabeng Municipality

By

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DISCLAIMER

The presentation of this thesis includes colour images to make the results more transparent and visually clear. While printing or viewing the thesis in greyscale (black and white) is possible, it is recommended that the thesis be viewed (or printed) in full colour for clarity.

DEDICATION

This thesis is dedicated to all my family members, in particular my beautiful wife, Mookho Kompi, for believing in me and always encouraging me to stay focused and strive for excellence, despite the challenges I faced throughout this exhausting journey. I am so blessed to have you in my life. God knows that without her wonderful, caring heart and patience, I would not have made it this far.

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To my beautiful mother, thank you very much for always being there to take care of my kids when I had to study on weekends and my wife had to attend to other family commitments. You are the greatest. I am also forever grateful for the love and support received from my mother-in-law and the whole family.

DECLARATION

This research, as presented in this thesis, is my original work and has not been offered for any other university award. Knowledge derived from different sources has been indicated, with acknowledgement and reference to the literature.

This study was conducted and completed under the guidance of Professor Muthoni Masinde, Department of Information Technology at Central University of Technology, Free State, South Africa.

Moabi Saul Kompi

Signature: ______________________

Date: 24 November 2025

In our capacity as the supervisors of this thesis, we certify that the above statements are accurate to the best of our knowledge.

Professor Muthoni Masinde

Signature:_____________________________

Date: 5 November 2025

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ABSTRACT

The empirical research discussed the smart city concept and the Smartness Assessment Framework (SAF) for municipalities in South Africa. It developed a mobile application using the Matjhabeng Local Municipality as a case study. The notion of smart cities comprises the integration of Information and Communication Technologies (ICTs), environmental sustainability, the functionality of municipal systems, quality of life for all, and, significantly, community-driven development. In South Africa, most municipalities use various assessment frameworks to guide operations, which may include basic components such as the municipal setting, ICTs, communities, and a development strategy. While the idea of smart cities is noble and desirable, it cannot be said of all medium-sized cities in South Africa, where an array of challenges makes the realisation of smart cities, especially in waste management, a pipe dream. At the top of the list of challenges are ineffective baseline physical infrastructure and poor-quality, unsustainable, and segregated social services. Furthermore, there are limited evaluation procedures on the smartness frameworks utilized by the municipality. In this study, the SAF is evaluated against six smart city best practices: smart governance, smart economy, smart people, smart living, smart environment, and smart mobility. Through the implementation and assessment of best practices, a mobile application technology solution has been developed to address the municipality's waste management and reporting challenges.

In terms of methodology, a mixed method was used to address the following objectives: 1) To carry out a systematic review of IoT deployment within smart cities implementations globally, 2) To review and assess the relevance and applicability of the smart city concepts, models and frameworks in use within three selected South Africa's municipalities, 3) To develop SAF for smart city implementations for South Africa's municipalities and 4) To develop a mobile app to assess waste management information system. To collect data, various methods were used, including interviews and document analysis, with reference to the Integrated Development Plan (IDP) reports, which helped develop an interview guide that shaped the proposed framework. The qualitative data were generated through interviews with 5 participants (directors) from distinct directorates within Matjhabeng municipality. To analyse the data, thematic analyses were conducted to generate insights for developing the SAF framework. Qualitative data gathered from the Community Services directorate were utilised to seamlessly develop the mobile application intervention, aligned with one of the framework's critical components, smart environment.

Quantitative data was generated from Statistics South Africa (StatsSA) database, focusing on IDP Matjhabeng Local Municipality, with reference to smart governance, smart economy, smart people, smart living, smart environment, and smart mobility. StatsSA, among other things, provided population demographics, economic growth levels, and infrastructure statistics, allowing insights into critical indicators such as population growth, service delivery performance, internet connectivity, and socioeconomic conditions. This data was critical in identifying gaps and possibilities for measuring smartness at work. To analyse quantitative data, the fuzzy synthetic evaluation (FSE) method was used to calculate the municipality's smartness index. Furthermore, the alignment of existing municipal objectives with smart city concepts was evaluated, with a focus on digital transformation, sustainable infrastructure, and effective governance. The integration of StatsSA and IDP datasets enabled a thorough evaluation of the framework and smartness performance, ensuring that ideas are grounded in evidence and contextually relevant.

Moreover, the thesis concluded with a contribution to smart municipal governance and environmental sustainability through the development and integration of a mobile application for waste management and reporting, offering a practical digital solution to improve waste collection, enhance citizen engagement, and promote environmental sustainability. In light of the above, the study argues that implementing SAF and the corresponding mobile application for waste management in Matjhabeng municipality required immediate attention and creativity, drawing on interviews, the IDP, and StatsSA data.

LIST OF ABBREVIATIONS

6LoWPANs	Wireless Personal Area Networks
AGSA	Auditor General of South Africa
AHP	Analytical Hierarchy Process
AI	Artificial Intelligence
ANN	Artificial Neural Network
APPL	Action-Plan-Policy-Law
AR	Augmented Realities
BLE	Bluetooth Low Energy
BRT	Bus Rapid Transport
CCTV	Closed-Circuit Television
CGICTPF	Corporate Governance of ICT Policy Framework
CLIAM	CAPTCHA-Like Implicit Authentication Model
CO_2	Carbon Dioxide
CoAP	Constrained Application Protocol
CODEX	Core Operations Development and eXchange
CoE	City of Ekurhuleni
CPS	Cyber-Physical Systems
CRCs	Cyclic Redundancy Checks
CSF	Critical Success Factors
DDoS	Distributed Denial of Service
DI	Development Index
DoS	Denial of Service
DPSA	Department of Public Service and Administration
DPWMS	Digital Participatory Waste Management Service Monitoring System
ESC	European Smart Cities
FSE	Fuzzy Synthetic Evaluation
GANs	Generative Adversarial Networks
GIS	Geographic Information System
GLMP	Greater Lanseria Master Plan
GPS	Global Positioning System
GUI	Graphical User Interface
ICMP	Internet Control Message Protocol

ICT	Information and Communication Technology
IDP	Integrated Development Plan
IDS	Intrusion Detection System
IoE	Internet of Everything
IoT	Internet of Things
IP	Internet Protocol
ISO	International Organisation for Standardisation
ITU	International Telecommunication Union
IWMF	Integrated Waste Management Facility
KAI	Kereta Api Indonesia
KPIs	Key Performance Indicators
KRL	Kereta Rel Listrik
KUDF	Kabul Urban Design Framework
LED	Light Emitting Diode
LoRaWAN	Long Range Wide Area Network
LOSI	Local Online Service Index
MCDA	Multi-Criteria Decision Analysis
MCDM	Multi-Criteria Decision Making
MF	Membership Functions
ML	Machine Learning
ML-IDS	Machine Learning Based Intrusion Detection Systems
MNU	MicroController Unit
MQTT	Message Queue Telemetry Transport
MSA	Municipal Systems Act
NDP	National Development Plan
NMWS	National Waste Management Strategy
OBPP	Ontology-Based Privacy-Preserving
OSCAR	Object Security Architecture
ProFiOt	Profiling Abnormality of IoT
PRTA	Proxy Re-encryption Trusted Authorisation
RFID	Radio Frequency Identification
RSC	Resilience Smart City
RSCAF	Reconciled Smart City Assessment Framework

SDGs	Sustainable Development Goals
SDLA	Skills Development Levy Act
SETAs	Sector Education and Training Authorities
SMART	Simplified Managed Applied Measured and Turned
SMS	Short Message Service
SNDGG	Smart Nation and Digital Governance Group
SPVs	Special Purpose Vehicles
SQL	Structured Query Language
SRC	Smart Resilience City
SSUDDF	Strategic Urban Development Decision Framework
StatsSA	Statistics South Africa
STEM	Science, Technology, Engineering, and Mathematics
SVM	Support Vector Machine
TCGA	Cryptography-based Group Authentication
TCP	Transport Control Protocol
TVET	Technical and Vocational Education and Training
USSD	Unstructured Supplementary Service Data
VR	Virtual Realities
Wi-Fi	Wireless Fidelity
WSN	Wireless Sensor Network
WPBL	Workplace-Based Learning

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PUBLICATIONS

As an outcome of this research, the author of this thesis is the first author of the published papers listed below.

Paper 1: Kompi, M. (2024). An Internet of Things and Smart Cities Frameworks Implementation in Municipalities: A Systematic Literature Review. In: Masinde, M., Möbs, S., Bagula, A. (eds) Emerging Technologies for Developing Countries. AFRICATEK 2023. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol 520. Springer, Cham. https://doi.org/10.1007/978-3-031-63999-9_2

CHAPTER ONE – INTRODUCTION

1.1 Background

Globally, discussions on smart cities and sustainable development are shifting their focus from traditional to smart governance paradigms (Bhattacharya, Bhattacharya, Mclellan & Tezuka, 2020). Considering the expanding debate surrounding complex issues related to social change, Tomal (2020) argues that smartness and sustainability are twin realities. The so-called smart cities that leverage new technologies to support the prioritisation and optimisation of service delivery, general management, and execution are moving from concept to viable reality (Das, 2024). Along the same lines, data-driven decision-making, which is aimed at achieving sustainable municipal planning and the integration of ICTs, is the main element of a smart city. Furthermore, the smart city concept extends to the implementation of systems that can self-govern, report issues, and make autonomous decisions based on predefined constraints to assist in optimising municipal worker efficiency (Pattanayak, Murthy & Mehra, 2024). These streamlined processes may, hypothetically, lead to municipal-level improvements that positively affect the private sector and urban residents. Just as municipalities seek to enhance service delivery through sustainability activities that include economic growth, so too does the smart city concept, which has gained prominence globally. For example, the idea is one of the potential responses used to increase the competitiveness of local communities and municipal areas, achieved through the application of innovative technological solutions to improve the quality of life for their citizens, providing better public services and a healthier environment. Nevertheless, in developing nations such as South Africa, assessing municipal levels of smartness remains a challenge. To bridge this gap, this study uses the understudied municipality as a case study to evaluate its performance and smartness level, utilising a proposed smart city smartness assessment framework (SAF). The aim is to guide the development processes by identifying key domains of smart city development, like Smart Government, Smart Economy, Smart People, Smart Living, Smart Environment, and Smart Mobility, used by Giffinger and Kramar (2021) and Desdemoustier, Crutzen, and Giffinger (2019) for medium-sized European cities, to provide a structured approach to measuring municipal smartness as a criterion.

The available governance systems, technological capabilities, and service delivery mechanisms vary significantly across different municipalities in South Africa. For instance, smaller municipalities such as Matjhabeng, as compared to metropolitan municipalities like the City of Johannesburg, the City of Ekurhuleni, and the City of Cape Town, which have begun adopting smart city initiatives, struggle with basic ICT infrastructure adoption (Maphangwa & van der

Waldt, 2023; Muridzi, Meyer & Masengu, 2021; Ncamphalala & Vyas-Doorgapersad, 2022; Molobela, 2025). Therefore, to achieve a specific level of smartness, these minor municipalities require a standardised framework to assess their smartness levels. In other words, this study addresses this gap by providing a measurable approach to evaluating municipal smartness through developing a tailored smart city SAF for this municipality.

Situated in the Free State province of South Africa, Matjhabeng Municipality serves as the focal case study in this thesis due to its unique challenges and developmental aspirations. The challenges faced by municipalities like Matjhabeng include, but are not limited to, financial constraints, governance incompetence, infrastructure weaknesses, limited technological advances, and, most importantly, backlogs in service delivery (Pira, 2021). Despite this, smart city interventions offer potential for transformation. According to the literature, important features related to a transformation that can be improved by ICTs include communication, community participation, public-private partnerships, transparency, and officials' accountability, which help make a municipality more liveable, sustainable, and efficient. However, other social factors besides smart technologies are fundamental for smart cities. Subsequently, this study will assess the smartness level by analysing other significant indicators, such as digital and mobility infrastructure, participatory governance, environmental sustainability, and citizen engagement, and providing insights through the application of a smart city SAF (Pereira, Guimarães, Cimon, Da Silva Barreto & Hermann Nodari, 2023).

The research aims to develop and implement a SAF that municipalities can use to determine their level of smartness. Establishing an evaluation framework is a significant goal for determining which municipal systems can improve city smartness and, ultimately, quality of life. Nevertheless, smartness requires the ability to handle much more complex scenarios than technology developed and installed in a laboratory. Therefore, key assessment criteria will be developed for this municipality that consider the smart economy, smart governance, smart people, smart living, smart environment, and smart mobility domains. Additionally, the practical evidence on municipal smartness assessment in this study will not only contribute to the growing body of knowledge in smart city literature but also, as municipal planners are formulating smart city policies driven by data (Sharifi, 2020), serve as a guiding tool.

1.2 Problem Statement

In megacities of developed countries, the concept of smart cities has already matured, as demonstrated by real-world applications in domains such as smart public transport, smart homes, and smart lots (Alabsi & Gill, 2024; Beckers & Mora, 2025). Acceptable smart city status is achieved when a city uses digital technologies to improve municipal performance and well-being, reduce costs, and effectively and actively engage residents (Akanbi, 2025; Das, 2024). However, the same cannot be said of medium-sized cities in Africa, where an array of challenges makes the realisation of smart cities a pipe dream. At the top of the list of these challenges are two issues: (1) ineffective baseline physical infrastructures and (2) poor quality, unsustainable, and segregated social services (IDP, 2023). For this reason, a generic design of a smart city for these contexts requires a middleware approach that leverages limited physical infrastructure to form a collective intelligent platform that supports procedures for governing and empowering citizens, as argued by Sethibe and Mabuza (2025).

In many municipalities in South Africa, semi-formal urban areas are often underserved in terms of infrastructure maintenance (Mabaso, 2018; Maphangwa & van der Waldt, 2023; Das, 2024). It is the thesis of this research that implementing a smartness evaluation framework to measure smartness performance in such areas and others could provide an overall picture of the status of this problem. However, it is notable that the evaluation framework is limited to the smartness of the systems and infrastructures utilised by the municipality. Due to the lack of a framework to assist the understudied municipality in assessing its municipal smartness status, the provincial and national remedial debate remains ineffective, remaining at the theoretical concept level.

1.3 Research Aim and Objectives

The overall aim of this research was to develop an assessment framework to act as a tool for evaluating the level of smartness within a local municipality in South Africa. The evaluation of this framework will be achieved through the implementation of a waste management and reporting system for a selected municipality in the Free State province. This aim will be achieved through the following specific objectives:

1. To carry out a systematic review of IoT deployment within smart city implementations globally.
2. To review and assess the relevance and applicability of the smart city concepts, models, and frameworks in use within three selected South African municipalities.
3. To develop an assessment framework for smartness in South African municipalities.
4. To use the case study of the waste management information system to evaluate the framework.

1.4 Justification of the Study

Due to poor service delivery, South African citizens are left with an infrastructure that is poorly maintained, deteriorating, and ineffective. It is noted that South African municipalities lack effective, accountable governance to deliver sustainable services to their citizens. It is not uncommon for citizens to picket or march to municipal premises, voicing their frustration with the municipality's failure to fulfil the basic services promised. Mine closures, thereby closing businesses in the mining industry; healthcare shortages; potholes across the country disrupting economic growth; the lack of police visibility in combating crime within society; and the illegal dumping of trash everywhere without any waste collection are just a few examples. The failures erode public trust, fuel criminal activity, and contribute to increased unemployment in the community, heightening concerns about societal safety. All these factors contribute to South Africa's overall economic instability. Despite this, Matjhabeng Municipality has suffered from inadequate budgeting for relevant infrastructure projects and mismanagement of service delivery.

The recent events mentioned above have made it evident that there is a need for an evaluation framework that, if successfully implemented, would provide scientific evidence of Matjhabeng's smartness status. Its role as the largest local municipality in the Lejweleputswa District, which includes Welkom and several other towns, serves as a vital motivation for this study, as it can be extended to other municipalities in the district. Due to the increasing challenges in this municipality, the implementation of the framework is necessary, as is a study of its evaluation successes and limitations to inform future improvements. Furthermore, the study's findings might help the municipality develop strategies tailored to its residents' needs.

1.5 Limitations and Delimitations

This study was delimited to a single municipality in the Free State province, the Lejweleputswa region, which comprises five municipalities. As a result, the findings can be applied to other similar municipalities but not metropolitan municipalities in the district, provincial, national, or international context. The suggested smartness framework is therefore tailored to the South African municipal context, particularly Matjhabeng Municipality. In addition, the study used only the framework's smart environment component to assess it. The smart waste management and reporting mobile application was used as an example; it is specialised for use in the municipal waste management and reporting department.

The study is further limited by its reliance on conventional statistical methods, such as the standard deviation, for indicator weighting. While useful for comparability, such measures do not necessarily reflect the socio-economic priorities of Matjhabeng residents. This limitation is acknowledged and addressed in the discussion and Future Work sections.

1.6 Significance and Contributions of the Study

This thesis contributes significantly to scientific knowledge through a novel approach that provides an SAF to measure the smartness degree of the Matjhabeng Municipality and other similar municipalities. This thesis will contribute to the present state of knowledge on smart cities' smartness by conducting novel research on an underserved topic in smartness assessment. There is a need for municipalities in South Africa to adopt approved approaches to assess their smartness performance as smart city initiatives gain momentum globally.

This study contributes a handcrafted structured SAF that enables decision-makers to evaluate their smartness level by adopting smart city principles. This framework provides six core universal domains utilised to assess different components of the municipality, namely smart governance, smart economy, smart people, smart living, smart environment, and finally, smart mobility. Each domain entails a specific set of indicators used as criteria to measure its different aspects and to determine, in percentage format, the domain's effectiveness. Additionally, a complete implementation and evaluation of this framework using both the IDP and StatsSA datasets was presented.

As a second contribution, a mobile application was developed to address technological challenges in conventional reporting and residential solid waste collection management. Solid waste is one of the sub-domains of the smart environment framework, in which this application provides technological solutions. Although such a solution could be provided for every aspect of the framework, this would require another study; hence, this study focused specifically on the smart environment domain. Through this novel mobile application, residents can report garbage collection issues, provide GPS locations and photos of illegally dumped garbage to the municipality, view scheduled collection dates, rank municipal collection services, receive updates on complaints to authorities, and interact with municipal officials in real time, among other things. Using this mobile application, officials can also issue reports to high-ranking authorities.

In conclusion, these contributions promote holistic accountability, efficient resource management, and sustainable municipal growth by bridging the gap between framework and technological innovation. This further results in improved public service delivery and a higher quality of life for residents by promoting a cleaner, smarter municipality that fosters innovative jobs.

1.7 Evaluation Criteria

This research assessment compared each objective to the study outcomes. The case study utilised to evaluate each study objective served as a measure of quality and dependability through verification and validation. Verification entails analysing the research project to ensure it meets the research objectives, whereas validation entails quantifying the research process using relevant validation measures.

1.8 Structure of the Thesis

Having introduced the study in the sections above, the remaining part of the thesis is structured as follows:

In Chapter 2, a comprehensive literature review is presented. This includes a conceptual clarification related to smart cities, municipalities, and local government in general. A few government spheres, including provincial, local, and municipal, are presented to provide a theoretical background for the emergence of local government, of which smart cities are a part. This chapter further focuses on smart city models and best practice approaches from leading smart cities, both locally and globally.

Chapter 3 provides insights and details on the methodology applied in this study. The main aim of this chapter is to provide data collection techniques, research design, and instruments used in this research, ensuring the research is valid, reliable, and addresses the aims and objectives.

Chapter 4 is the core chapter that presents the framework for assessing the municipality's smartness. The researcher focuses on outlining different parts of the framework. The critical domains of the smart city framework, drawn from the interviewed participants' smart governance, smart people, smart living, smart environment, smart mobility, and smart economy, are presented and addressed in detail, along with sub-domains for each domain.

On the other hand, Chapter 5 presents an evaluation of the framework using secondary data from StatsSA, as well as an integrated development plan (IDP) document. Data is analysed, and the findings are discussed and presented to demonstrate the municipality's level of smartness.

In Chapter 6, an empirical study addressing Objective 4 involves developing a mobile application to test the study framework, with a specific focus on waste management and reporting. The study conducted an extensive systematic literature review to gain insights and draw on experience from developed countries, and used interview techniques to collect data on the app's development.

Finally, Chapter 7 concludes the study with a synopsis. The chapter provides a summary of the study by reflecting on the key points covered across all chapters. The chapter further recommends an innovative city framework for Matjhabeng Municipality as part of its contribution to new knowledge. This addresses the main aim of the study outlined in section 1.3 of Chapter 1, namely the development of a SAF for the conditions of the Matjhabeng Local Municipality. This chapter also proposes recommendations for future research.

1.9 Summary

This chapter presented an overview of smart cities, emphasising their role in using technology to improve citizens' quality of life. The research problem of rapid population growth and the integration of smart technology was highlighted. The research aims and objectives were established. The study's limitations and delimitations were explored, clarifying the scope and constraints under which the research was undertaken. The chapter concluded with an explanation of the study's significance and contributions, offering valuable insights and practical solutions to the current discussion of smart city development. The second chapter, to follow, will include a literature review.

CHAPTER TWO – LITERATURE REVIEW

2.1 Introduction

The focus of this chapter is to present a review of the literature on smart city concepts and frameworks. The chapter commences with the smart city concept and the definitions that form the discipline within which the study is rooted.

2.2 Smart Cities

Literature asserts that there is no universal definition of a smart city. According to Desdemoustier *et al*. (2019), the concept of a smart city is not consistently defined. However, scholars and practitioners seem to agree that any smart city should aim to deliver a highly sustainable, thriving, and inclusive future for citizens by effectively integrating the physical, spatial, digital, and human worlds (Ncamphalala & Vyas-Doorgapersad, 2019). Likewise, DAS (2015) and Javed, Shahzad, Rehman, Zikria, Razzak, Jalil and Xu (2022) posit that a city can be deemed a smart city if it exhibits a combination of qualities that include entrepreneurial ecosystem, innovation, information and communication technology (ICT) usage, and IoT to increase operational efficiency, connectivity, mobility, governance, citizen welfare, development, deployment, and promotion of sustainable development practices to fulfil the ever-growing demands of citizens. Smart cities address various challenges in cities today, focusing on improving the quality of life for city residents. However, there are several challenges involved in their implementation, as Roessing and Helfert (2021) point out. Marchetti, Oliveira, and Figueira (2019) share Pira's (2021) view that, to be a smart city, cities need to reduce inequalities, prioritise and expand territorial and economic integration, put people first, and emphasise technology as a tool primarily serving citizens. This development, according to Pira (2021), not only focuses on the technical aspects of the concept of smart cities but also promotes their potential impact on urban studies and projects. Besides, smart cities should provide more transparent, sensible, and collaborative decision-making processes, both within and outside government.

2.2.1 Definitions of Smart Cities

Bhatia, Sachdeva, Vats, and Gandhi (2025) describe the smart city as a cycle comprising numerous ICTs, maintenance, development platforms, sustainability, apps for evolving citizens, and key social, technical, and economic performance indicators (KPIs). Intelligent cities use ICT advances and innovative practices to improve quality of life, accelerate economic growth, maintain a safe, sustainable environment, and streamline urban management (HamaMurad, Jusoh & Ujang, 2021). Ezugwu, Hashem, Oyelade, Almutari, Al-Garadi, Abdullahi, Otegbeye, Shukla, and Chiroma (2021) define a smart city as one that supports the judicious use of resources and the timely delivery of services. A smart city integrates the functions of its various systems and makes them work together coherently by utilising new technologies, specifically leveraging data to make the best possible decisions (Lai, Jia, Dong, Wang, Tao, Lai, Wong, Zobaa, Wu & Lai, 2020). Almulhim and Yigitcanlar (2025) point out that the smart city concept enables cities to utilise existing infrastructure, collaboration tools, and platform-based automated service management to enhance safety and efficiency, and to attract stakeholders and citizens. Smart cities, as a concept, have been defined differently by these authors; thus, there is no unified or standard definition across the literature.

On the other hand, since the inception of the concept of smart cities, most key industries have been involved in advancing smart city technologies, also known as domains. They range from smart mobility, smart people, smart living, smart governance, and smart economy to smart environment. The common feature among them is the direct and/or indirect engagement of the community (Desdemoustier *et al*., 2019; Giffinger & Kramar, 2022). Community-based visions are vital to developing smart solutions to collective problems, not technology in and of itself (Keshavarzi, Yildirim & Arefi, 2021). Likewise, Karuri-Sebina and Guya (2020) argue that to discover effective smart solutions, a problem-driven, rather than a technology-focused, approach is needed. The key domains and their indicators for smart cities are presented in Figure 2.1. These six domains of the smart cities concept will be discussed further in the next section.

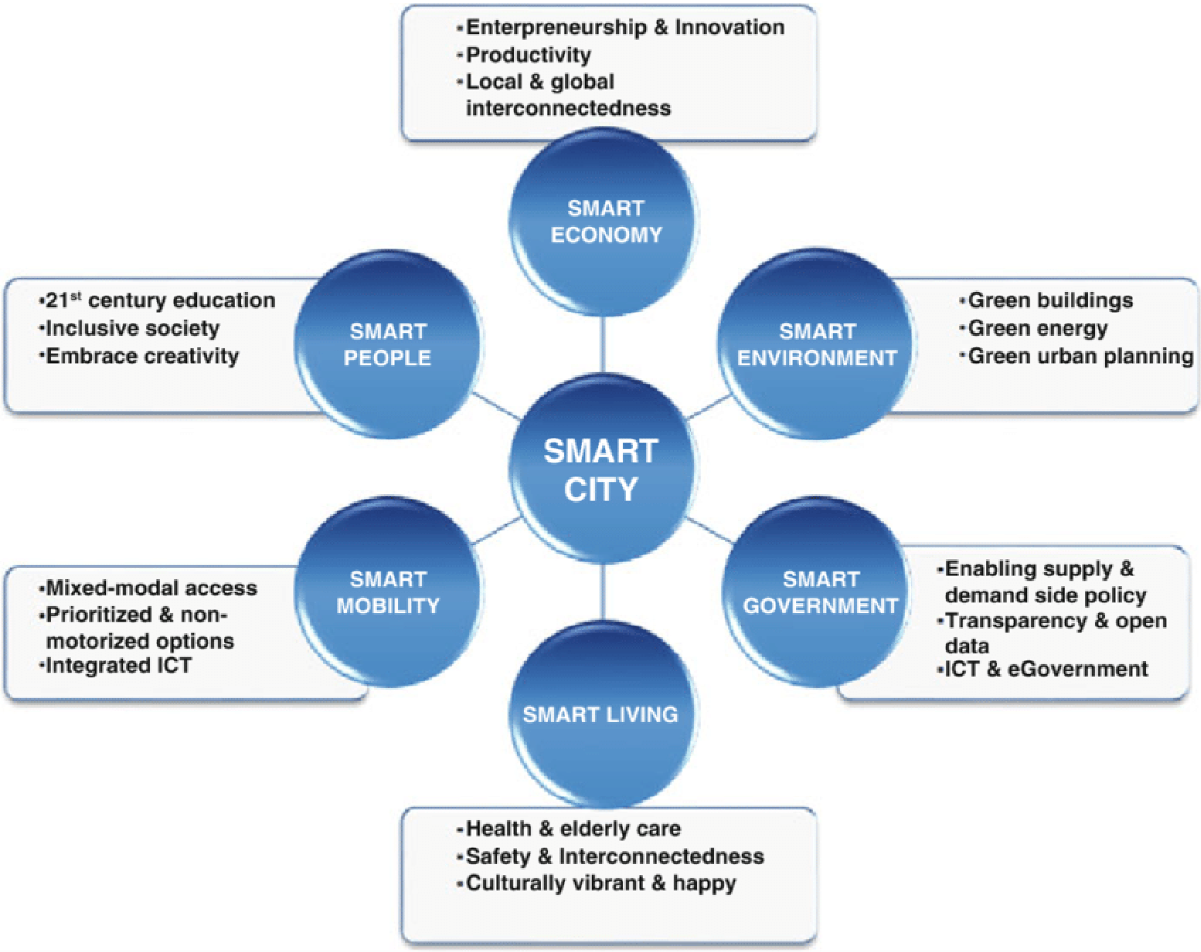

Figure 2.1: Key Domains and Primary Indicators for Smart Cities, adapted from Sharifi (2020)

According to Giffinger and Kramar (2022), a smart city is a city that combines self-determination, independence, and awareness with endowments and activities across the six key areas depicted in Figure 2.1 to achieve success. Often, smart cities are referred to as digital or intelligent cities from a technological perspective, as Mokoena and Sebola (2020) maintain. Similarly, according to Falus (2022), a smart city is one in which traditional networks and services are enhanced using digital technologies, hence improving performance for residents and businesses. However, Pira (2021) argues that the concept of smart cities differs from other related concepts, such as digital, technological, and intelligent cities. However, it is universally agreed that the development, effectiveness, and success of the smart city concept require the integration of several ICT elements. In this sense, Pira (2021) further suggests that ICTs are not one of the main pillars of smart cities, but they do play a role in supporting the development of smart communities. Community engagement further requires that the implementation be open and transparent and incorporate all economic, social, and emotional aspects of human life (Lee, Koster, Arias, Lim, Zeng, Phy, Kolassa, Liu, Duc Dang, Laverde-Barajas, & Jayasinghe, 2025). Thus, humans and digital devices are the foundation of smart cities. As described earlier, they include human actors (such as citizens, city operators, administrative institutions, public and private companies, etc.) and digital devices (such as city sensors and actuators used in a variety of domains, like mobility and transportation, environment, energy, healthcare, governance, robotics, industry 4.0, etc.), smart homes and smart buildings, and personal devices (Bellini, Nesi & Pantaleo, 2022). Karuri-Sebina and Guya (2020) assert that, according to the International Standards Organisation, sustainability in a smart city is achieved more rapidly through social, economic, and environmental outcomes while addressing challenges such as climate change, rapid population growth, and political and economic instability. This is to more effectively engage society, apply collaborative leadership methods, and work across disciplines and city systems that need to fundamentally improve how they engage society. The viewpoint of the pair (Karuri-Sebina & Guya, 2020) is that by utilising modern technology and data, the city can deliver better services to residents, businesses, and visitors now and in the years to come, without restricting the natural environment or unfairly disadvantaging others. Figure 2.2 below shows the generic architecture of IoT for a smart city.

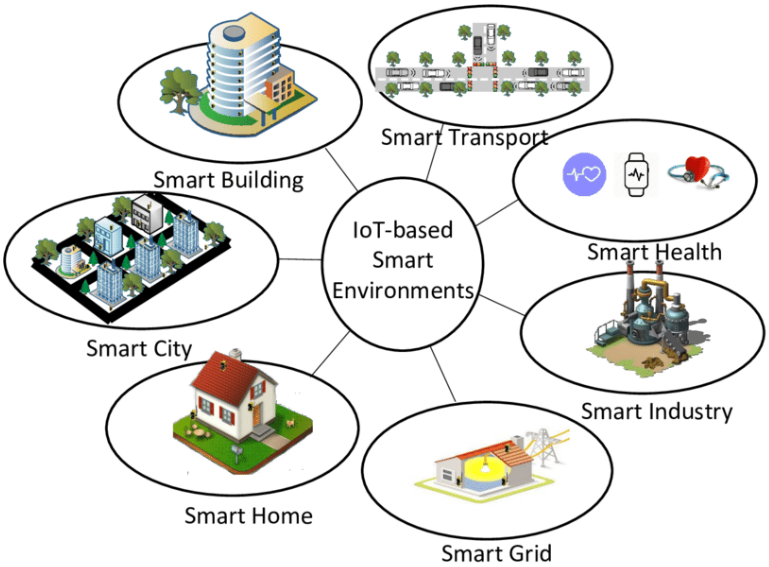

Figure 2.2: Generic IoT-based Smart City Architecture, adapted from Hamamurad, Jusoh, and Ujang (2022).

The smart city vision focuses on the growth of both cities and industry without disrupting facilities for future generations (Jayashree, Ramya, Malarvizhi, & Kumaresan, 2021). In addition, this vision requires IoT implementation to create various aspects of daily life related to citizenship (Medina, Perez, & Trujillo, 2017). Thus, according to Karuri-Sebina and Guya (2020), using technology appropriately is not about implementing technology solutions so much as about using it in ways that allow cities to do things differently. This, in turn, supports improvements in people's quality of life through a metropolitan network of things that significantly enhance safety using sensor technologies (Khatoun & Zeadally, 2016; Medina *et al*., 2017; Bhatia *et al*., 2025). Smart cities aim to address tomorrow's challenges by continually seeking innovative solutions (Inac & Oztemel, 2021).

2.2.2 Domains of the Smart Cities

The previous section highlighted six major domains of the smart city concept: Smart Mobility, Smart People, Smart Living, Smart Governance, Smart Economy, and Smart Environment, as outlined by Giffinger and Kramar (2022). These domains are critical to the successful transformation of any city into a smart city (Muthaiyah & Zaw, 2021). A brief discussion of these domains of the brilliant city concept, each followed by its specific indicators, is to follow.

2.2.2.1 Smart Governance

In smart government, according to Shayan, Kim, Ma, and Nguyen (2020), technology-driven planning, management, and operations are optimised across a variety of domains, process areas, and jurisdictions, thereby making them more efficient, practical, and cost-effective. Besides certifying the quality and integrity of data, the government can also facilitate financial mechanisms, coordinate stakeholders, involve citizens throughout the value chain, and publicize smart city projects both internally and externally (Lai *et al*., 2020). As part of such governance entities, citizens are typically involved in the promotion, execution, financing, warranting, certification, and decision-making of projects in the city as an international requirement for sound transparency (Sabory, Senjyu, Danish, Ahmadi, Zaheb & Halim, 2021). For example, citizens were actively engaged in decision-making and urban planning through social e-participation as part of smart city governance in the study by Szarek-Iwaniuk and Senetra (2020), and Sabory *et al*. (2021) shared the same view. The study explored community members' opinions and perspectives (Łaźniewska, Janicka & Górecki, 2021), enabling authorities to gain a richer understanding of how to manage cities and meet residents' needs. Likewise, Vodák, Šulyová, and Kubina (2021) assert that Smart London Camp is a city management initiative that enables citizens in London to participate in a public debate and express their views on smart city projects. Moreover, with the Smart Nation and Digital Governance Group (SNDGG), Singapore has implemented several smart governance projects, including a digital identity system for residents of Singapore that enables them to more easily perform transactions with government agencies and a digital platform for delivering innovative services to Singapore residents, namely the Core Operations Development and eXchange (CODEX) (Bellini *et al*., 2022). Having the above in mind, technological advancements, too, have a substantial impact on the effectiveness of public governance, not just on how services are delivered but also on the skills required to utilise new technologies (Govender & Reddy, 2019).

This domain encompasses public engagement, citizen services, and efficient, transparent administration (Pira, 2021).

2.2.2.2 Smart Economy

With many people moving to cities, managing infrastructure and creating a sustainable economy has become increasingly complex. Therefore, smart city initiatives should develop information technology capabilities and set new agendas for market development and smart industry actions to stimulate the economy (Li, Liu, Wang, Zheng, Lv & Lv, 2022). Also included in this domain is the concept of a sharing economy, in which individuals or private companies offer services using their assets and through peer-to-peer markets (Bellini *et al*., 2022). A smart city should combine innovation, entrepreneurship, productivity, a flexible labor market, and the integration of national and global markets as key economic factors. This is exemplified by Huawei Company, according to Akbarpour, Haranaki, Gharibnavaz, and Sharif (2021), which has developed an exceptional ecosystem communication strategy that relies on artificial intelligence between smart devices, with the smartphone at the centre, and that works with a wide range of devices such as personal computers, laptops, tablets, watches, and wearable clothing. So, in a smart economy, smart environments, mobile technology, and human capital are the cornerstones of innovation (Appio, Lima & Paroutis, 2019).

Entrepreneurship, innovative spirit, flexibility, labour market productivity, trademarks, and participation in international markets are some indicators of this domain surrounding economic competitiveness (Lai *et al*., 2020).

2.2.2.3 Smart People

It is almost impossible to underestimate the importance of changing a person’s mentality (Popova & Sproge, 2021). Hence, to create a city that effectively demonstrates the characteristics of a smart city, one must first pay attention to what citizens have to say (Makieła, Stuss, Mucha-Kuś, Kinelski, Budziński & Michałek, 2022), as innovative solutions will be determined by their needs. Developing citizen competencies and fostering knowledge acquisition are the best ways to achieve this goal. High school graduates, however, do not have the same advantage; this result highlights the importance of knowledge intensity when increasing employability. Universities and other higher education institutions are essential to the development of human capital in smart cities, leading to positive, substantial impacts on economic growth (Appio *et al*., 2019). The first and most important factor for smart city project success is citizen engagement, together with governance as a secondary factor, presuming that, in practice, technology is only an enabler and not a source of technology-based smart city initiatives. According to Gupta, Zhang, and Hall (2021), a smart city cannot develop without smart and responsible citizens who understand their responsibilities, not merely their rights.

The indicators of this domain include not only citizens' educational backgrounds but also their social interactions, innovations, and perceptions of public life (Lai *et al*., 2020).

2.2.2.4 Smart Living

There is always a compromising choice, and prioritising and making decisions about well-being, health, and happiness always affects future cities and their development (Sassen & Kourtit, 2021). Hence, according to Demong, Shahrom, Omar, Abdul Rahim, and Yahya (2021), the concept of social well-being entails maintaining an active and purposeful social life that strengthens and sustains our sense of well-being. Thus, for a city to realise the possibility of smart living, initiatives need to be seen to improve social services, education, and health, as well as citizen participation in city planning (Waseem Anwar & Ali, 2022). By improving healthcare, providing easy and quick access to information on government portals, and enhancing quality of life, amongst others, these initiatives contribute to smart living (Varghese, Pathak & Varde, 2021). For instance, IoT has the potential to improve the service quality of the healthcare system, mainly through the collection of patient data and through improved patient care and safety, which could lead to an overall improvement in patient life expectancy (Nižetić, Šolić, López-de-Ipiña González-de-Artaza & Patrono, 2020). Similarly, with more than 6,000 CCTV cameras installed across Jakarta, the Indonesian government could detect floods and brawls in advance (Syalianda & Kusumastuti, 2021). In addition, the availability of Wi-Fi in several public places in Jakarta has significantly increased network access, enabling the collected data to be shared quickly among all city residents.

This domain includes many aspects of quality of life, including health conditions, housing quality, educational facilities, cultural awareness, tourist attractions, and personal safety (Lai *et al*., 2020; Pira, 2021).

2.2.2.5 Smart Environment

The concept of an innovative and/or sustainable environment is built around green technologies, a principle of doing more with less, and the use of technology to improve sustainability is core to the concept of a smart city in terms of protecting and managing natural resources, such as waterways, canals, aqueducts, and parks (Moch & Wereda, 2020). Lai *et al.* (2020) are of the view that, with smart cities developing competitive business environments, IoT applications can be deployed in any smart environment, including telecom, finance, manufacturing, logistics, retail, parking, transportation, and hospitality, and the cities can then attract skilled labour and human capital and build outstanding physical, hardware, and software infrastructure (Rao & Deebak, 2023). For example, one key observation in the smart environment field is that most applications use the cloud to store large amounts of heterogeneous data collected from IoT sensors (Yigitcanlar, Mehmood & Corchado, 2021). Likewise, a key component of Singapore's solid waste management system is the Integrated Waste Management Facility (IWMF), which incorporates innovative IoT technology to enhance process efficiency and reduce greenhouse gas emissions (Bellini *et al.*, 2022). Accordingly, green spaces in urban environments also help to cool down the temperatures of cities, which has positive impacts on plants, animals, and humans, as well as health goals like promoting well-being and preventing illness, thus ensuring long-term sustainability and resilience, beneficial to all, but especially to vulnerable targets, according to Ertl, Müller, Aal, Wulf, Tachtler, Scheepmaker, Fitzpatrick, Smith and Schuler (2021).

2.2.2.6 Smart Mobility

Unnecessary traffic congestion, resultant air pollution, noise, and traffic accidents are among the most serious problems in cities now that more people drive cars, which, among other things, puts people's lives in danger through emissions (Inac & Oztemel, 2021). Most smart city projects aim to reduce congestion in urban areas, and this is one of their primary motivations. However, it is vital to note that, in cities, human mobility relies not only on vehicles but also on citizens and the infrastructure that supports them (Ribeiro, Dias & Pereira, 2021). Public transport includes traditional modes such as taxis, buses, metros, and trains. Various solutions are available, including independent vehicles that reduce the need to own a car and sensors designed to enhance the effectiveness of critical infrastructure such as roads, railways, subways, bridges, tunnels, seaports, and airports (Appio *et al.*, 2019). An Intelligent Transportation System (ITS) is a concept in transportation that utilises technology to enable smart mobility (Nasution, Erwin & Risanty, 2020). One such example is the Kereta Api Indonesia (KAI) access application for intercity trains, the Kereta Rel Listrik (KRL) access application for inner-city trains, and Tijeku for Trans Jakarta. The Jakarta government has built a transportation network integrating physical and digital infrastructure to facilitate travel between the city and satellite cities and to provide public data transparency to facilitate mobility (Syalianda & Kusumastuti, 2021). Trans Jakarta bus stops, train schedules, bus locations, and station locations are available to the public through the application. Additionally, research carried out by Bielińska-Dusza, Hamerska, and Żak (2021) shows that while the city of Kraków, Poland, was implementing smart city solutions to reduce congestion and crowded streets, measures such as an increase in bus lanes, a priority system at intersections that favours public vehicles, and a traffic light system based on the volume of traffic have not had any positive impact on the perception of the reliability of public transportation on the part of its users.

In addition to local and global accessibility, sustainable and relevant transportation systems are regarded as indicators that contribute to both (Pira, 2021).

2.3 Internet of Things (IoT) within Smart Cities

Literature on IoT applications in smart cities is abundant (Bellini *et al*., 2022). IoT, broadly understood as the network of distinct '*things*' in our modern daily lives, continues to play an immensely critical role. IoT uses interoperability, heterogeneity, distributed processing, and real-time analytics to establish reliable communication, monitoring, and management between smart embedded devices and their analogue counterparts or things (Abdelaziz & Mesbah, 2021). The viewpoints of Abdelaziz and Mesbah (2021) and Jena, Biswal, Anil, and Lenka (2022) are that as IoT matures and evolves, it will become one of the most hyped concepts in the IT world. It also promotes the idea that a global network of physical objects will enable global connectivity at anytime, anywhere, not just for one individual, to exchange data without human involvement, as shown in Figure 2.3. Accordingly, smart cities are urban management concepts that efficiently collect, manage, and interpret data using sensors and the IoT (Setijadi, Darmawan, Mardiyanto, Santosa, & Kristanto, 2019). Improvements to smart city infrastructure, along with the use of ICT and the IoT, provide valuable data for the successful monitoring of assets and resources (Arun Sekar & Sasipriya, 2021). In the same vein, such environmental improvements further enable ease of data collection from sensor networks, space platform technologies, web services, and citizen participation platforms, as well as traditional static sources from surveys and historical records, referred to as citizen-sourced and/or social media data collection, respectively (Caird & Hallett, 2019). Increasingly, IoT is a key enabler of more brilliant innovation and sustainable development in smart cities, where it drives more brilliant innovation (Bellini *et al*., 2022).

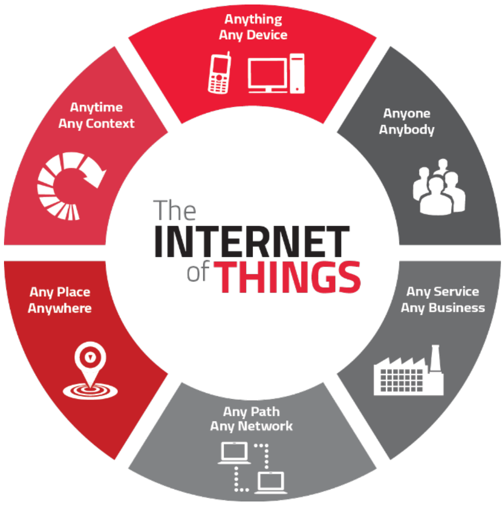

Figure 2.3: Internet of Things Generic Test Scenario (www.conceptdraw.com)

2.3.1 Definitions of Internet of Things

The IoT enables everyday devices to communicate with each other and with the Internet, according to El-Hajj, Fadlallah, Chamoun, and Serhrouchni (2019). Balaji, Nathani, and Santhakumar (2019), supported by Jena *et al.* (2022), define IoT as an association of interconnected machines, devices, animals, or people that possess unique identifiers and can exchange data over a network without human-to-human or human-to-machine communication. Bhatnagar and Kumra (2020) refer to IoT as billions of physical devices connected to the internet that collect and share data, such as smartphones, wearables, fashion items, and smart home appliances. The global user community has yet to define IoT in a unified manner, despite the definitions mentioned earlier. According to Abdelaziz and Mesbah (2021), while the term originated with Kevin Ashton, an expert in digital innovation, several groups, including researchers, developers, practitioners, innovators, and corporate individuals, have defined it. Sergi, Montanaro, Benvenuto, and Patrono (2021) assert that, through industrial IoT, companies can improve productivity, reduce costs, and create new revenue streams, thereby competing more favourably in the long run. Likewise, business assets can be better managed through automation and intelligence, resulting in smoother business processes and more efficient resource allocation. As IoT has become an essential component in future smart cities, Guo, Shen, Bashir, Imran, Kumar, Zhang, and Yu (2020) maintain that great strides have been made in the past decade.

2.3.2 Internet of Things Technologies

The industry in the digital age is rapidly changing, and Wireless Sensor Networks (WSNs) are key to this transformation. Devices are expanding rapidly, creating the opportunity to connect the unconnected for faster insights. There are many challenges and opportunities in the modern business environment, which relies heavily on data (Nozari & Fallah, 2021); thus, new sources of information can be used to develop solutions that enhance business quality and improve the relevance of business activities. Network protocols, therefore, enable amicable communication between connected devices through predefined syntax, conventions, and data structures. As pointed out by Siokas, Tsakanikas, and Siokas (2021), a key requirement for data is technology. Hence, through IoT utilisation, businesses can effectively integrate data into their daily operations and services (Siokas *et al*., 2021). The traditional industry is changing with the advent of Industry 4.0, and wireless sensor and actuator networks are key to this new way of doing business (Majid, Habib, Javed, Rizwan, Srivastava, Gadekallu & Lin, 2022).

Having all the above in mind, IoT technologies are rapidly being applied in various spheres of the urban landscape on a scale, scope, and complexity unlike anything humankind has experienced (Čolaković, Džubur & Karahodža, 2021), intending to advance all sectors beyond that of mere human capability (Yang, Shen & Cetin, 2021). Some of the existing IoT technologies and communication protocols utilised to connect physical devices and virtual objects are identified by Vaigandla, Karne, and Rao (2021) and Imran, Alshahrani, Fayaz, Alghamdi, and Gwak (2021) as:

- Wi-Fi: According to literature, Wi-Fi has been commonly mistakenly described as ‘Wireless Fidelity,’ but its name originated as an attempt to give a catchier name to the newly invented wireless technology widely known as ‘IEEE 802.11b Direct Sequence.’ Vaigandla *et al*. (2021) and Imran *et al*. (2021) hold that Wi-Fi is another widely used internet protocol that enables communication between IoT and physical devices, with a range of approximately 50 feet.
- Wireless Sensor Network consists of specialised transducers connected by a network infrastructure for monitoring and recording conditions at different locations, including temperature, humidity, pressure, wind direction and speed, illumination intensity, vibration intensity, sound intensity, power-line voltage, chemical concentrations, and

pollutant levels. A novel perspective on this technology is presented in Almurisi and Tadisetty (2022).

- Long Range Wide Area Network (LoRaWAN) refers to a low-power, low-cost, mobile, and secure wireless technology and is optimised for scalable networks with millions of wireless devices with low power consumption and very low cost (Vaigandla *et al*., 2021; Imran *et al*., 2021). Likewise, it can detect signals below the noise floor over long distances, enabling IoT applications to detect weak signals.

Furthermore, other main IoT technologies identified by several conducted studies constitute the key components of IoT architectures (Muthaiyah & Zaw, 2021; Kumar, Sehgal, Kumar & Singh, 2019; Witti & Konstantas, 2018; Lakshmi, 2018). These include:

a. standards required to enable IoT to embrace web services and connect devices, machines, and tools to the internet employing wireless technologies;
b. a microcontroller unit such as Node MCU or Arduino UNO;
c. communication network infrastructure;
d. intelligent control and management;
e. sensor networks;
f. smart feature and automatic response, and
g. short-range connectivity technologies such as Bluetooth and ZigBee, and GPS-based remote-controlled devices.

In terms of IoT technologies, it is not possible to prioritise one over another, as each technology discussed has different applications under different conditions (Vaigandla *et al*., 2021). For instance, through the International Telecommunication Union (ITU) platform, IoT devices can transmit data to city infrastructure for analysis and integration into all city applications (Gavrilović & Mishra, 2021). As part of the ITU platform, the authors provide a summary of four core layers, presented in Table 2.1.

Table 2.1: ITU and IoT Layers, quoted from Gavrilović and Mishra (2021)

Layers	Solution
Sensing Layer	The network consists of sensors monitoring the city's physical infrastructure, as well as sensor nodes connected to the network.
Network Layer	Connects city networks provided by city telecommunications companies.
Data and Support Layer	Data collected from city terminals, services, and applications is stored in this database.
Application Layer	Citizens, managers, and businesses can access a range of services and applications.

2.3.3 Internet of Things Security

In this interconnected world, networks, with a focus on wireless networks, are exposed to a wide variety of attacks, such as (but not limited to) denial of service, spoofing, and eavesdropping. According to Kassab and Darabkh (2020), to address these issues, IoT systems have been developed to incorporate multiple security features, including privacy protection, authorisation controls, authentication measures, data encryption, content validation, and message authentication. Sensors, devices, machines, wireless communication networks, cloud storage, and the appropriate software solutions are all highly vulnerable integral parts of IoT, making privacy, security, and trust mandatory, according to Balaji *et al.'s* (2019) study. Likewise, a few challenges are involved with connected things, including connectivity issues for billions of devices to communicate with one another and security issues protecting IoT networks against attacks, as reported by Kim, Son, and Park (2025). Integrity is a key security attribute that defines authentication, accuracy, and completeness of data and information related to IoT services and applications, as well as security and privacy issues affecting their implementation. Thus, keeping the system and data secure is what data integrity is all about (Sharma, Joshi, Kannan, Govindan, Singh, & Purohit, 2020).

To maintain data privacy and confidentiality, secure communication is vital to IoT architecture, according to El-Hajj *et al*. (2019). They further indicate that privacy regulations regarding data collection, storage in memory, and the sharing of details should respect the individual's privacy. Accordingly, it is unlikely that users will be attracted to IoT if there is no strong confidence in privacy, no solid infrastructure to address security issues, and no adequate infrastructure to address potential problems IoT might face (Balaji *et al*., 2019). Methods to raise users' understanding of the consequences of potential IoT risks may reduce their vulnerability (Farias da Costa, Oliveira, & de Souza, 2021). A reliable communication protocol is required to utilise encryption and authentication measures.

The previous sections discussed that network interoperability should consider data security, and a well-integrated IoT architecture would provide a protective layer for data, as there is no single unified IoT architecture (Farias da Costa *et al*., 2021). Likewise, various designs have been suggested for the IoT environment (HaddadPajouh, Dehghantanha, Parizi, Aledhari & Karimipour, 2021). However, a thought-provoking study by Kassab and Darabkh (2020), based on extensive readings of prior relevant surveys and books, popularised the concept that the IoT stack comprises five layers: perception, data link, network, transport, and application. Equally, Padhi and Charrua-Santos (2021) found that a five-layer, three-dimensional security architecture is necessary in IoT systems, as it addresses various security issues and requirements.

HaddadPajouh *et al*. (2021) provide a summary of the architectures grouped into three classes, presented in Table 2.2.

Table 2.2: Architectures Classes, quoted from HaddadPajouh *et al*. (2021)

Architecture	Description
Three-layered	This class is widely seen in many publications and among colleagues in the research world. It follows a top-down format with three layers: Application, Network/Transmission, and Perception/Edge.
Four-layered	This class is organised in much the same way as the three-tiered architecture, however, with an extra layer for application and service.
Five-layered	Two elements are reflected in this architecture: A business layer located above the application layer to provide numerous features for each IoT domain, and a sub-layer in the edge layer for IoT applications that are crucial at the device level.

2.3.4 IoT Security and Threats Challenges

HaddadPajouh *et al*. (2021) state that, regardless of the architecture of IoT systems, there are numerous potential risks at each level of the IoT framework. An extensive array of security threats, also known as attacks, can emerge from dynamic and heterogeneous networks that support the IoT (Farias da Costa *et al*. 2021). The description of attacks on IoT systems is always based on a specific layer due to the complexity of understanding which attacks are identical, which mechanisms they depend on, and whether they apply to other protocols (Tournier, Lesueur, Le Mouël, Guyon & Ben-Hassine, 2021). A summary of the five layers of

IoT architecture, as given by El-Hajj *et al*. (2019), Kassab and Darabkh (2020), HaddadPajouh *et al*. (2021), and Tournier *et al*. (2021), is provided in Table 2.3.

Table 2.3: Categorising IoT Architecture Description and Related Threats, from El-Hajj *et al*. (2019), Kassab and Darabkh (2020), and Tournier *et al*. (2021)

Layer	Description	Threats	Counter Measures
Perception	Sensors, including RFID, WSN, and GPS, are used in this layer to detect the physical characteristics of devices in an IoT network.	*Denial of Service (DoS)* - Shuts down the network by flooding it with multiple messages to prevent access by authorised users.	Reconfigure your operating system to disallow Internet Control Message Protocol (ICMP) responses to IP broadcast requests.
		Denial of Sleep - Prevents the node from entering required sleep after sending the appropriate sensed data.	Multi-layer-based intrusion detection system, coordinated sampled listening based on the MAC protocol, and/or Software-Defined Network-based IoT.
		Distributed Denial of Service - Malicious Remote Terminal Units send hundreds of random IP packets to the Master Terminal to overload the system and make it unusable.	GANs (generative adversarial networks) defend against overload attacks by predicting new attacks and enabling Software-Defined Network-based IoT.
DataLink	Organisations list various standard technologies for the IoT data link layer, such as Bluetooth, ZigBee, RFID, low-power wide-area networks, Z-Wave, and cellular.	*Denial of Service* - Uses a fake node to jam radio signals, affecting data routing between nodes.	Software-Defined Network-based IoT.
		SQL Injection - Degrades system integrity through malicious code insertion into an SQL-using server.	Static/Runtime Analysis.
Netwo	The network layer comprises switches, firewalls, bridges, and routers that use communication and routing protocols such as	*Authentication and secure communication* - Security vulnerabilities arise from the overhead of cryptographic algorithms.	Lightweight ticket-granting system, applying symmetric and asymmetric encryption systems for encrypting packet payload dispatch type values while collecting logs.

Layer	Description	Threats	Counter Measures
rk	3G, 4G, 5G, Wi-Fi, infrared technology, ZigBee, and fibre-to-the-x to create logical connections.	*Eavesdropping/sniffing* - Allows a hacker to listen to a private message over a communication link, potentially revealing usernames and passwords, node identification, and node configurations.	Point-to-point authentication of incoming packets.
Transport	This technology facilitates the transition between the application layer and the transmission of error-free data, ensuring reliable data transmission.	*Data Transit* - Lacks data encryption and authentication mechanism (Tsiknas, Taketzis, Demertzis & Skianis, 2021).	The Secure Message Queue Telemetry Transport (MQTT) protocol, an attribute-based encryption (ABE) algorithm, can be adapted to create scalable and robust security mechanisms.
		SYN-flooding - A malicious device sends SYN packets to the victim, preventing legitimate SYN requests from being processed (Tsiknas *et al.*, 2021).	An optimisation in the transport layer involves network filtering.
Application	Takes processed data from the network layer and provides IoT project developers with various interfaces, platforms, and tools to build applications.	*Insecure interfaces* - Targeted as a point of vulnerability in their hosting environments.	Password strength verification, secure coding (SQLi and XSS), and installing application gateway firewalls.
		Constrained Application Protocol (CoAP) security - Lack of encryption systems to secure communications.	Secure application Proxy and Resource Directory.

It is essential to use a variety of security measures to safeguard IoT architecture against different attacks and potentially malicious software (Kassab & Darabkh, 2020). Thus, research pursuits that develop mechanisms to protect against threats and/or attacks using machine learning and deep learning, coupled with novel detection techniques, are essential, according to Padhi and Charrua-Santos (2021). Similarly, Wheelus and Zhu (2020) conclude that machine learning has the potential to be effective at preventing some attacks.

Cybersecurity and privacy concerns can be mitigated through authorisation, encryption, authentication, and public-key infrastructure-based approaches, according to Harrath, Adohinzin, Kaabi, and Saathoff (2025). Similarly, the study conducted by Padhi and Charrua-Santos (2021), supported by Azrour, Mabrouki, Guezzaz, and Kanwal (2021) and Kim *et al*. (2025), found that industries need to ensure safe and secure connectivity by managing security at every level of IoT systems, protecting objects and users' identities, and implementing multifactor authentication, authorisation, integrity, confidentiality, non-repudiation, availability, and privacy in protecting identities rather than gateways.

Authentication must verify that remote use of a device is legitimate on a public network to prevent unauthorised users from accessing private networked communication. Generally, authentication is performed using a legitimate user's credentials and passwords. These credentials should be changed regularly, and computers should not be left unattended.

Authorisation defines the access control rules that allow or deny permissions to IoT devices, and the security service responsible for determining user rights and privileges (read, write, or delete).

Integrity prevents an unauthorised object from being illegally modified, and it guarantees that the receiver has received precisely what the source sent. Data integrity can be ensured using cryptographic mechanisms, for example, when the data being transmitted is highly sensitive.

Confidentiality refers to how well a system can prevent unauthorised users from accessing private information. IoT devices, for example, use encryption algorithms and cryptographic methods to protect personal information captured by sensors and prevent it from being compromised.

Non-repudiation ensures that participants in remote communication can send or receive information in its entirety, and that data or identities can be transferred between IoT objects undeniably. An example of non-repudiation is when a source node sends its data and the receiving node confirms that the received data matches the source data.

Availability assures that the intended users have access to the services and objects they need, wherever they are and at any time. An example of this is that to ensure that adequate resources are available, a distributed approach is used, allowing systems to be integrated remotely via various platforms.

2.4 Internet of Things Implementations within Smart Cities

So-called smart cities that employ and embed new technologies to assist in prioritising and optimising traditional services, such as infrastructure maintenance, and to revolutionise general municipal planning and execution, are moving from concept to viable reality (Abdelaziz & Mesbah, 2021). In other words, the implementation of machines and systems that can self-govern, report issues, and make autonomous decisions based on a preconceived set of restrictions can assist the smart cities' human municipal role-player in optimising his or her efficiency (Möhlmann, Gregory & Henfridsson, 2025). Hypothetically, these streamlined processes will lead to improvements in municipal government, bringing benefits to the private sector/business and to urban residents.

As a result of IoT, human life has changed dramatically, especially in communication and technological integration (Majid *et al*., 2022). In a highly connected IoT environment, devices collect data about their own state. Afterwards, a network connection transmits data to a cloud server or to a reliable, effective database that stores and processes it (Uganya, Radhika & Vijayaraj, 2021). Subsequently, this data can then be accessed via a user interface, allowing devices and assets to be remotely monitored or controlled. Technological innovations can enable smart city citizens to connect to city tools and services. IoT innovation, advancement, and implementation across smart cities profoundly influence many intertwined systems, such as the environment, economy, and transportation (Razmjoo, Gandomi, Mahlooji, Garcia, Mirjalili, Rezvani, Ahmadzadeh, & Memon, 2022). Sustainable smart industries have shown considerable interest in IoT, as it offers improved operational efficiency (Nozari & Fallah, 2021).

A study on IoT-based smart streetlight systems by Arjun, Stephenraj, Kumar, and Kumar (2019) presents the smart streetlight system as a significant infrastructure that continues to utilise IoT concepts. As part of the Jakarta Smart City program, Jakarta has built physical infrastructure by creating a centralised streetlight system that connects more than 90,000 LEDs (Syalianda & Kusumastuti, 2021). The Indonesian government's efforts to integrate a centralised streetlight system with automatic sensors allow the dematerialisation of electrical energy in Jakarta. The study further deliberates on and demonstrates how smart streetlight systems can efficiently address socio-economic problems, such as health, road accidents, crime reduction, energy waste, repair, and maintenance costs, thereby enhancing people's safety and security.

Tong, Ye, Yan, Liu, and Basodi (2021) support the view of Mokoena and Sebola (2020), who state that, based on their understanding of the concept of a smart city, they believe that, inter alia, a smart city is a combination of a digital and IoT infrastructure and edge computing.

Additionally, Desdemoustier *et al*. (2019) take a step further, noting that improvements in ICT and other smart city technologies, when combined, enhance effectiveness and efficiency in the city. Further, digital technologies offer more efficient and effective logistics processes and help cities have a better understanding of their performance by allowing cities, municipalities, authorities, industries, couriers, security officers, research centres, universities, start-ups, technology companies, and others to be more involved in decision-making processes (D'Amico, Taddeo, Shi, Yigitcanlar & Ioppolo, 2020). This shows that IoT can only be an enabler; alone, it is not adequate to transform a city into a smart one, according to Muthaiyah and Zaw (2021). This is supported by Demong *et al*. (2021), who argue that IoT, combined with Artificial Intelligence (AI), Machine Learning (ML), Internet of Everything (IoE), and Cyber-Physical Systems (CPS), amongst others, can greatly assist. The IoT is changing the world, making everything quickly and effectively accessible in a smart world. Besides technological implementation, when formulating a policy strategy, policymakers must consider the uncertainties in a municipality's social, financial, and cultural environment, as well as the needs of all stakeholders (Siokas *et al*., 2021).

2.5 Smart City Implementation Approaches within Municipalities Globally

The emergence of smart cities within municipalities globally has become a central issue. In this regard, local governments utilise integrated smart city frameworks as a key municipal strategic plan to shape both society and cities through appropriate existing technologies (Almulhim & Yigitcanlar, 2025; Khatibi, Wilkinson, Baghersad, Dianat, Ramli, Suhatril, Javanmardi & Ghaedi, 2021). Although the concept of smart cities emerged as an idealistic, visionary approach to city development, technological advancements such as AI and IoT have necessitated a pragmatic, operational examination of available frameworks (Tzioutziou & Xenidis, 2021). The application of new technologies has become crucial across many domains, requiring increased energy efficiency, reduced emissions, and the facilitation of new forms of communication (Giffinger & Kramar, 2022). That is why many cities are embracing new technologies as essential tools for urban development to meet the new challenges comprehensively. The municipality's goals, objectives, and indicators should be the focus (Bastidas, Bezbradica & Helfert, 2017). However, it is paramount that companies developing and/or implementing new technologies strive to establish close relationships with actors outside their traditional partner networks, such as government and society, when addressing complex societal problems, including climate change, urbanisation, and pandemics (Leite, 2022).

Similarly, Afonso, dos Santos Brito, do Nascimento, Garcia, and Álvaro (2015) proposed the Brazilian Smart Cities Maturity Model. This framework provides a high-level view of five layers: S (Simplified), M (Managed), A (Applied), R (Measured), and T (Turned), which are summarised by the acronym SMART. Therefore, SMART projects become the purpose of the selected area when they are driven by the vision, goals, and strategic intent (Vodák, Šulyová & Kubina, 2021). Two municipalities were assessed through this framework, and the outcomes have shown children completing primary school education, a proportion of people without access to safe drinking water, and the spread of HIV/AIDS beginning to reverse (Afonso *et al.*, 2015). Abu-Matar (2016) also developed the Smart City Reference Architecture Meta-Model (smartCityRA) framework and further refined it to allow the extension of data view (Anthony & Sarshar, 2025) to measure weather data such as temperature, humidity, and precipitation for the city of Abu Dhabi (Abu-Matar, 2016; Roessing & Helfert, 2021).

Antwi-Afari, Owusu-Manu, Ng, and Asumadu (2021) conducted an influential study on the smartness and smart developmental levels of cities in developing countries, grounded in the city of Kumasi, Ghana. They provided more insight into these six imperative smart city concept domains (Desdemoustier *et al.*, 2019; Giffinger & Kramar, 2022) and, interestingly, adopted this framework, which focused on classifying and understanding the ideas an urban framework holds about Kumasi City. Experts in academia and industry who are knowledgeable about urban development or urban domains were targeted and selected for the study (Oke, Aghimien, Aigbavboa & Akinradewo, 2020). Using participatory weighting to assess smartness and smart development levels for each dimension, eight indicators were developed based on a systematic review of the literature and on existing indicators from a conventional study (Antwi-Afari *et al.*, 2021). The implications from the study analysis demonstrate that the smartness/smart development level of the city can be enhanced through improved performance on key indicators within each dimension, including (Antwi-Afari *et al.*, 2021):

1. People Dimension: Digitalising and educating the city's human resources.
2. Economy Dimension: City investments, resource consumption, and standard of living enhancement.
3. Mobility Dimension: Adoption of renewable energy vehicles and emerging technologies to improve accessibility and inclusion of the abled and the disabled in the city.
4. Environment Dimension: Creating infrastructures that are in harmony with the environment so the city can be green, safe, and affordable.

5. Governance Domains: Implement a transparent governance system where all aspects of city life, such as taxes, health, crime reporting, and voting, are assessed electronically.
6. Living Dimension: Encouraging social inclusion and improved healthcare systems in cities.

According to Antwi-Afari *et al*. (2021), Kumasi City may also be considered fairly developed based on the overall indices of smart development across all six domains.

The European Smart Cities (ESC) approach is a concept developed by Giffinger, Fertner, Kramar, and Meijers in 2007 and adapted by Giffinger and Kramar (2022). The duo highlighted six key areas (Smart Mobility, Smart People, Smart Living, Smart Governance, Smart Economy, and Smart Environment) of urban development, which were further subdivided into 33 relevant domains. A further subdivision into 74 indicators defined the domains of each city (Moustaka, Maitis, Vakali & Anthopoulos, 2021), utilising data from various European data sources. However, the latest version of ESC reduced the number of implemented domains even further, down to 31. As a result of the ESC approach, cities were able to coordinate better, draw mutual lessons, and exchange best-practice examples (Moustaka *et al*., 2021), while also tracking progress and planning improvements over time (Giffinger & Kramar, 2022). The objective was to gather insights into data-driven individual city profiles to provide a clear picture of understudied cities at varying levels of detail, thereby helping stakeholders uncover what smartness means locally (HamaMurad *et al*., 2021). As a result of this approach, empirical evidence was not only provided on city profiles in a differentiated manner, but also groups of cities with similar profiles were identified. Likewise, Razmjoo *et al*. (2022) completed, categorised, and examined research publications based on an extensive review of literature that focused on the problems and solutions of several key sectors that have significant implications for smart city development, such as public transportation, utilities, street lighting, waste management, public safety, and smart parking. As part of the analysis, they looked at important cities within the European Union (Paris, London, Copenhagen, Barcelona, Amsterdam, and Oslo) and in the USA (Boston, New York, and San Francisco) that are relevant to the IoT.

Table 2.4: IoT Barriers and Appropriate Solutions for the Development of Smart Cities, summarised from Razmjoo *et al*. (2022)

Sectors	Barriers	Solution
Public transport	As the number of private cars increases, noise from private vehicles in cities rises. Monitoring patterns of citizens' transportation use is not being fully utilized. Roads are unsafe and inefficient. Traffic congestion, sudden accidents, and deficient roads are all leading factors contributing to increased CO_2 emissions.	Improve GPS systems by utilising data from drivers' smartphones and using proper patterns. Use monitoring sensors to improve road quality by utilising different types.
Utilities	Fuel and electricity are wasted; fuel and electricity expenses are unnecessarily high; smart meters and smart billing are misused; knowledge of consumption patterns is limited; and citizens have limited opportunities to monitor their consumption remotely.	Improve service quality by using T-equipped smart meters, optimized consumption patterns, and management services.
Smart parking	Parking options for drivers are limited or non-existent, cars are parked improperly on the street, and routes are narrowed by traffic.	Using GPS data from drivers' smartphones or embedded sensors in parking spots to determine location (Abdelaziz & Mesbah, 2021).
Waste management	Due to inefficient systems for tracking when waste should be collected, garbage is discharged, leading to unpleasant odours in cities. Fuel losses and empty containers result from the lack of accurate systems to monitor the correct time to collect waste.	Waste containers can be fitted with sensors to track waste levels and optimise waste collection schedules.
Environment	Water and air quality monitoring have been neglected amid rising CO_2 emissions and threats to public health.	Sensors such as water, air, and other types can be used to enhance monitoring accuracy.
Public safety	Crime such as robbery is on the rise in cities, the law and regulatory rights are not being enforced, and infrastructure is lacking.	To maintain security and privacy, IoT infrastructure will use IoT technologies such as CCTV cameras and acoustic sensors. Undoubtedly, this will improve interoperability, leading to vendor lock-in and control corruption (Abdelaziz & Mesbah, 2021).

In conclusion, the ESC aimed to provide a highly differentiated indicator-based evaluation of smart city characteristics in an easily comprehended way, followed by place-based approaches that collected and combined comparable data of urban development and provided empirical results on three levels (Calzada, 2021), including a group of indicators at the bottom level, a group of domains at the mid-level, and a group of key city characteristics at the top level (Giffinger & Kramar, 2022). Essentially, the authors envisioned ESC as an approach that can successfully assess the smartness performance of cities, with a large set of indicators describing each domain. Giffinger and Kramar (2022) argue that a key finding of the study was that the same approach can be used to select cities with similar structures, challenges, and problems, thereby facilitating the sharing of learning processes and knowledge transfers between cities. The ESC versions are summarised in Table 2.5.

Table 2.5: ESC Versions for Assessment Approach, summarised from Giffinger and Kramar (2022)

ESC version	Description
ESC-1, 2007	Allows for a set of six partner cities that must meet specific criteria, which can be compared using available local data. Data has been collected using mandatory domain indicators to determine inclusion in the city sample.
ESC-2, 2013	A total of 82 indicators were added, some data sources were updated, and other cities expressed interest in participating in the evaluation, reducing the number of participating cities to 71, while the basic criteria remained unchanged.
ESC-3, 2014	A sample of 81 indicators for urban development is included in the ESC-3 2014 assessment model, which allows transparent profiling and benchmarking of comparable and competing cities across Europe, drawing on the experiences of the previous two versions.
ESC-4, 2015	In 2015, Krakow and the Polish region of Malopolska requested strategic advice on developing this smart city development strategy. ESC-4 moved its focus from almost 800,000 individuals to cities with 300,000 to 1 million inhabitants across Europe, leading to the development of new indicators.

Giffinger and Kramar's (2022) ESC approach facilitates shared learning processes and knowledge transfer by selecting cities with similar structures, challenges, and problems.

Through a systematic literature review, D'Amico *et al*. (2020) created a Smart and Sustainable Logistics in Port Cities framework that holistically integrates a variety of enabling factors, domains, and goals that frame smart and sustainable logistics in port cities. The proposed framework highlights the following enabling factors: Both (1) ecosystems and (2) organisations, emphasise an active role and flexible organisational interaction among various stakeholders, including port managers, planners, administrators, entrepreneurs, citizens, couriers, students, port authorities, road and rail transport companies, technology companies, financial institutions, etc.; (3) data and security and (4) policy and regulation underscore the complexity of digital technologies, with security levels that encompass data and information from multiple stakeholders. Accordingly, (5) finance and funding highlight the importance of tax leverage to trigger worthy logistics developments. Through the support of technology companies such as Cisco, IBM, SAP, Ericsson, and Huawei, an in-depth analysis of several pioneering port cities was carried out, including Amsterdam, Rotterdam, Antwerp, Los Angeles, Valencia, Hanan, Montreal, Stockholm, Hamburg, Singapore, and more (D'Amico *et al*., 2020). For example, with Cisco Edge Intelligence software, the Port of Rotterdam uses a multi-cloud dashboard to analyse, interpret, and refine data from patrol vessels to improve logistics and operations (Tang, Jayakar, Feng, Huiping & Peng, 2019; D'Amico *et al*., 2020). Likewise, as part of IBM's logistics infrastructure solutions, sensors, IoT platforms, and augmented intelligence platforms are integrated, enabling them to collect, process, and provide data on weather, berth availability, and other metrics (Tang *et al*., 2019; D'Amico *et al*., 2020). In addition to improvements in information collection, processing, monitoring, analysis, and evaluation, the framework enhances the smartness and sustainability of urban and industrial processes by harmoniously integrating mobility, economy, governance, environment, telecommunications, health, safety, and so on, according to D'Amico *et al*. (2020) and Bellini *et al*. (2022).

Afghanistan's capital, Kabul, has experienced rapid growth, expanding to its outskirts and transforming horizontally and vertically over the past two decades; significant funds are being spent on infrastructure for transportation, water, energy, and ICT, but this investment is not aligned with urban smart and sustainable agendas (Sabory *et al*., 2021). The city was designed to house 0.8 million people, but has now grown to 4.9 million. According to Sabory *et al*. (2021), the Kabul Urban Design Framework (KUDF) is a legal and policy document ratified by the Afghan government as the framework for Kabul's future urban development. Sabory *et al*. (2021) propose a generic framework for integrating sustainable and smart energy into the urban planning processes of low-income developing countries. A four-stage action proposed framework, also known as Action-Plan-Policy-Law (APPL), is comprised of four key steps: (1) the development of laws and regulations, (2) the development of policies, (3) the preparation of relevant plans, and (4) the implementation stage (Sabory *et al*., 2021). After adopting the generic framework, two new sustainable and smart energy frameworks have been developed: the Afghanistan Urban Sector Energy Framework and the Kabul Municipality Energy Framework (Sabory *et al*., 2021). Legislation, policymaking, and government structure are the former's responsibilities, while planning and implementation are the latter's (Razmjoo *et al*., 2022). Notably, its benefits include improving the nation's urban and energy sectors, increasing public participation, reducing corruption, and improving public trust in government (Razmjoo *et al*., 2022). Furthermore, analysis of smart and sustainable urban infrastructure strongly supports the view that transparency is essential for attracting investment and securing funding from funding agencies, as well as for satisfying citizens (Razmjoo *et al*., 2022). As identified by Razmjoo *et al*. (2022) (cycle lanes, walkability, bicycling, and public transportation), the framework also supports sustainable infrastructure, affordable housing, and urban mobility, in addition to economic empowerment and efficient resource use (Tsonkov, Petrov & Berberova-Valcheva, 2022). APPL is a planning tool, whereas the KUDF framework requires coordination with related government departments and stakeholders, local community participation in the planning process, and the collection of actual data on the sites. From this viewpoint, using the KUDF framework, the energy sector in Kabul can implement plans, such as installing smart meters, to achieve economic feasibility, environmental protection, and practical implementation (Sabory *et al*., 2021).

Siokas *et al*. (2021) conducted a comprehensive study, evaluation, and mapping of the implementation status of a smart city-oriented strategy across various Greek municipalities. A detailed assessment of internal processes and potential challenges was conducted, along with an evaluation of technological, financial, and social advances already adopted. Accordingly, they investigated both the technological and institutional factors that influence the current strategy initiatives. In response, a conceptual framework for a smart city was developed, which considers a city as a social, economic, and technological system composed of institutional factors (D'Amico *et al*., 2020) and anthropocentric facets. As a result of internal processes within a municipality (Giffinger & Kramar, 2022), this framework reflects the city's policy strategy and its actual urban environment, which vary from municipality to municipality (Siokas *et al*., 2021). It comprises three phases related to smart city formation: (1) assessment of the importance of smart city initiatives during the planning phase (phase I), which refers to the initial strategy design by public authorities; (2) degree of integration of those initiatives being deployed in a city (phase II); and (3) the fully functional smart city, where a select set of initiatives are deployed to transform an urban area into an intelligent one (Siokas *et al*., 2021). Essentially, when planning, implementing, and assessing a strategy, Sabory *et al*. (2021) argue that a municipality should consider several factors. Siokas *et al*. (2021) emphasise the importance of considering local issues and concerns. This study evaluated the planning phase and the level of implementation according to five thematic areas/phases: (1) energy, environment, quality of life, and transportation in the city; (2) the financial situation of a municipality; (3) the promotion of innovation; (4) citizen skills enhancements; and (5) e-services made available to citizens. For an innovative and sustainable city to be successful, a systematic approach to smart and digital actions and a favourable social and economic environment may be necessary (Siokas *et al*., 2021; HamaMurad *et al*., 2021; Giffinger & Kramar, 2022).

Based on their extensive review of literature on exploring smart city project implementation risks in Kakinada and Kanpur, Gupta and Hall (2022) identified seven kinds of risks associated with smart city project implementation that can be summarized as resource management and partnership, institutional, scheduling and execution, social, political, technological, and financial. These are itemised in Table 2.3. In this context, the authors argue that assessing smart city implementation risks is of paramount importance in the cities of Kakinada and Kanpur, which are undergoing redevelopment under the Government of India Smart Cities Mission (SCM), including specifically the research question asked: What are the most prominent risks of retrofitting the smart city model? (Gupta & Hall, 2022). Furthermore, through a smart city strategy, the Indian SCM encourages industry visitors and engages them in smart city development projects, thereby improving residents' quality of life through innovative planning. Likewise, the strategies laid the groundwork for a framework that enables city managers and smart city initiative implementers to assess the risks involved in successfully implementing smart city initiatives, according to Gupta and Hall (2022). Table 2.6 indicates that this study focused on government officials and industry professionals but did not include academic perspectives on current smart city projects in India.

The Integrated Framework to Measure Smart City Readiness (IFMSCR) assesses the development of a smart city across technological and non-technological aspects, including political and societal support for smart city initiatives (Noori, de Jong, & Hoppe, 2020). Hence, the IFMSCR values technological and non-technological aspects equally when assessing readiness levels. Cities can then consider both elements when developing their respective smart city initiatives. This makes this framework more comprehensive and integrated, as the non-technological aspect is also considered a critical success factor for a smart city project. Noori *et al*. (2020) base their IFMSCR on qualitative data analysis of scientific papers and existing frameworks for smart cities readiness, such as the Input-Output model of the smart city development process, which characterises inputs, throughputs, outputs, and outcomes of the smart city development process, and the smart city readiness guide by the Smart City Council, amongst others.

Another integrative framework proposed to gain a holistic perspective of smart cities is the Smart City Integrative Framework (SCIF), designed by Chourabi, Nam, Walker, Gil-Garcia, Mellouli, Nahon, Pardo, and Scholl (2012). They examine a wide range of literature across various disciplines to identify eight critical factors for smart city initiatives. The eight areas of the SCIF are as follows: management and organisation; technology; governance; policy context; people and communities; economy; built infrastructure; and the natural environment. These eight factors form the basis of an integrative framework for examining how local governments envision smart city initiatives (Chourabi *et al*., 2012).

Table 2.6: Seven Types of Smart City Project Implementation Risks, adapted from Gupta and Hall (2022)

Types of Risks	Origins of the Related Risks	Example
Resource Management and Partnership	According to Gupta and Hall (2022), the presence of multiple stakeholders, existing ownership of assets or land, and network performance are all factors to consider.	Study findings indicated that in both Kakinada and Kanpur, government officials were concerned that large corporations well-versed in smart city concepts were not interested in investing in smaller cities because of lower project costs.
Scheduling and Execution	It can result from weak regulatory institutions in cities, which prevent the strict enforcement of city policies (Bruton *et al*., 2007).	Industry professionals highlight the lack of integration between ongoing and proposed projects, caused by poor planning and insufficient citizen training on new technologies, as well as the fact that the proposed timeline is often unrealistic, as most of the time is spent collecting data.
Social	As a result of citizens' lack of understanding of the smart city concept and its intentions (Gupta & Hall, 2022).	Government officials and industry professionals agree that smart city projects can be effectively implemented only if citizens adhere to enforcement policies that facilitate their implementation.
Technological	Gupta *et al*. (2020) identified three factors contributing to technology adoption: technology infrastructure, technology selection, and technology implementation.	The lack of a policy framework concerning the use of digital platforms for citizen data collection and use raised concerns among industry professionals.

Types of Risks	Origins of the Related Risks	Example
Financial	Projects with major funding issues may be hindered (Gupta & Hall, 2022).	Because smart city projects are large and expensive, poor financial planning can delay completion due to insufficient funds at critical stages.

This therefore suggests that integrating the two frameworks can significantly assist in developing the proposed framework for a desirable smart city.

2.5.1 Comparative Analysis of Smart City Frameworks

Cities of varying sizes and socioeconomic backgrounds have developed smart city frameworks. Using these frameworks, an integrated smart city can be assessed, ranked, and provided with guidance. Several frameworks for assessing smart city readiness were discussed in the preceding section. In Table 2.7, these frameworks are compared.

Table 2.7: Comparative analysis of smart city frameworks

Frameworks	Key Domains	Similarities
European Smart City Ranking Model	This was designed for medium-sized European cities, using six smart characteristics: economy, people, living, government, environment, and mobility.	This model provided a foundation for most subsequent smart city approaches.
Kabul Urban Design Framework	It is an Afghan government legal and policy document ratified as the framework for Kabul's future urban development.	Focuses on integrated sustainability, inclusive growth, mobility, governance, and urban development
Smart and Sustainable Logistics in Port Cities Framework	Digitalisation, environmental sustainability, intermodal connectivity, port city integration, stakeholder collaboration, and resilient infrastructure development.	Digital innovation, sustainability, multimodal connectivity, and collaborative governance for efficient and resilient urban systems.

Frameworks	Key Domains	Similarities
Smart Cities Maturity Model and Self-Assessment Tool	Stakeholder engagement, data, technology, governance, and service delivery models are all integral parts of a strategic intent.	Ensures cities are measuring their smart city maturity level against predetermined goals.
Smart City Reference Model	Besides the traditional elements, there are also the elements of environment, interconnection, instrumentation, integration, application, and innovation.	A city's maturity level is measured using a layered approach.
Smart Cities Mission	Smart cities guidelines are nationally devised.	To attain sustainability and good governance, ICT is an essential enabler.
Integrated Framework to Measure Smart City Readiness	Political readiness assessment, social and technological domains.	Investigates the relationships among technological, social, and political factors that influence a city's smart readiness. Aspects of technology and non-technology are valued equally.
Smart City Integrative Framework	Management and organisation; technology; governance; policy context; people and communities; economy; built infrastructure; and the natural environment.	It uses domains like those of the European Smart City Ranking Model. It categorises the domains into external and internal elements, without and with, respectively, some level of control by a city.

2.6 Smart City Implementation Approaches within South African Municipalities

In South Africa, according to Ngomane and Khatleli (2021), following the Municipal Demarcation Board (MDB), municipalities are divided into various categories (A, B, and Cs), such as metropolitan municipalities, district municipalities, and local municipalities. These operate under the Municipal Structures Act and Constitution and are listed in Table 2.7. The primary responsibilities of these authorities are to provide and maintain services to their communities, including water utilities, solid waste collection, electricity, and firefighting services. In every municipality, decisions are made by the council, and municipal officials and staff carry out the municipality's work (Saba, Ngepah & Ohonba, 2022). The metropolitan level is the largest, followed by the district, which comprises a few local municipalities that fall under one district (Gumede, Byamukama & Dakora, 2019). Districts, as well as local municipalities (also known as non-metropolitan areas in South Africa), form part of a local sphere of government, which, in turn, makes up a part of the nine provincial governments that constitute the national government (Simon, Vora, Sharma & Smit, 2021). According to Maphumulo and Bhengu (2019), the three distinct, interdependent, and interrelated spheres of government (local, provincial, and national) each have unique functions, as presented in Table 2.7. Likewise, South Africa's municipalities are an essential source of service delivery; the provincial government coordinates and supports municipal activity, and national departments are required to play a more strategic role in supporting local and provincial government (Cooper, Coetzee, Blom, Chauke & Ndlovu, 2025). A lack of strategic coordination among government spheres has resulted in task duplication, and a lack of clear leadership and expectations from municipalities has hindered service delivery (Khambule, 2021).

Table 2.8: Descriptions of Municipal Categories in South Africa (Mathebula, 2018)

Classification of Municipalities	Municipalities	Description of the Municipal Categories
A	Metropolitan	Select executive and legislative authority.
B1	Local	Largest budget and secondary cities.
B2	Local	A municipality with a central large town.
B3	Local	A relatively small, mainly urban population with no large town as a core.
B4	Local	Mainly a rural municipality with, at most, one or two small towns.
C1	District	Few service delivery functions; not a water service authority.
C2	District	A water services authority and often with sizeable obligations.

In South Africa, as in many other African countries, decentralisation has led to the responsibility of national economic development being more reserved to sub-national (provincial and local) governments (Iddawela, Lee & Rodríguez-Pose, 2021). Sub-national governments have played an essential role in bringing people together in various forms within societies outside the capital city, as local governance policies and actions are more influential than national ones (Iddawela *et al*., 2021; Robinson & Stephens, 2021). However, in setting up large-scale projects with significant environmental impacts, such as airport construction, waste management plants, subway systems, and metropolitan systems, for example, the powers of national and provincial governments essentially take precedence (Simon *et al*., 2021). Such environmental impacts, however, do not fall within local governments' jurisdiction, as Simon *et al.* (2021) maintain. Therefore, the crucial role of South Africa's local government cannot be overemphasised. It is for this reason that Khambule (2021) contends that, as the primary provider of services, the local government sector often requires more revenue to meet its needs than the national or provincial government.

Audits conducted by the Auditor General of South Africa (AGSA) in municipalities led to the development of the Corporate Governance of ICT Policy Framework (CGICTPF), which found that smart technology governance was not effectively practised (Sibanda & von Solms, 2019; Govender & Reddy, 2019). According to the authors, all public entities, including municipalities, were required to implement the CGICTPF in 2012 when the Department of Public Service and Administration (DPSA) introduced it. The phased implementation of the CGICTPF has proved a challenge for municipalities, as neither milestones were met nor were functional practices put in place (Govender & Reddy, 2019). As such, it is unlikely that municipalities will realise smart city smart solutions as effectively as they could if effective smart governance practices are not implemented (Sibanda & von Solms, 2019). Seemingly, in terms of digitalisation, South African cities still have a lot to accomplish to attract investors; hence, to prepare for the Fourth Industrial Revolution (also called Industry 4.0 or 4IR), South Africa must significantly strengthen its leadership and governance processes across all spheres of government, particularly at the municipal level, as it lacks citizen or elected representative accountability (Govender & Reddy, 2019; Simon *et al*., 2021).

According to Razmjoo *et al*. (2022), there are many stakeholders to consider when planning the proper implementation and establishment of policies for a smart city, including enterprises, citizens, and institutions of learning. For instance, a team of professionals appointed by the Gauteng Provincial Government and the Presidency completed the draft Greater Lanseria Master Plan (GLMP) two years after President Ramaphosa announced his vision (related to the previously mentioned visions) for a smart city in South Africa (Plessis & Wood, 2021). As part of the Lanseria Smart City, 430 km2 will be covered, spanning three metropolises - the City of Johannesburg Metropolitan Municipality, the City of Tshwane Metropolitan Municipality, and Mogale City Local Municipality - sharing a border with Madibeng Municipality in the Northwest, according to Plessis and Wood (2021). They argue that the development of Lanseria Smart City is, or should be, a public-led initiative and cannot be driven solely by developers.

However, it must acknowledge the developers' critical role as the primary driver for its implementation. Ideally, this city aims to provide high-quality, predictable, and affordable public transport, while encouraging a local population that lives, works, learns, prays, and plays in the same places (Plessis & Wood, 2021). They intend to make Lanseria Smart City a walkable, bike-friendly locale with non-motorised transport routes; they encourage the use of high-occupancy vehicles such as the Rea Vaya bus (Plessis & Wood, 2021). Another study by Das (2020) conducted a case study in Bloemfontein to evaluate perspectives on smart cities. The study focused on the perspectives of stakeholders who participated in the focus group, which included, amongst others, metro municipal council members, experts in urban development, and, importantly, community members (Nelson, Toth, Linders, Nguyen & Rhee, 2019). The outcome of this study was suggestions for prioritising sectors such as the economy, mobility, and governance to transform a city into a smart city. The study also resulted in three independent conceptual models for smart city development (Das, 2020).

The general smart city indicators have been identified as follows (Das, 2015; Nelson *et al*., 2019; Das, 2020):

a. Economy indicators: Entrepreneurship endeavours, labour productivity, and flexibility.
b. Mobility indicators: Transport network per resident, public transport accessibility, public transport quality efficiency, and emission-free mobility system.
c. Governance indicators: Most importantly, a transparent and responsive governance system, effective citizen participation and social services, as well as the needs of a city to reinforce it to be termed as a smart city.

To investigate and nurture sustainable smart cities in South Africa, Mokoena, Musakwa, and Moyo (2017) argue that better decision-making, through the application of evidence-based scientific planning, is required. In proposing a strategic framework for urban development, Mokoena and Sebola (2020) utilised methods such as the Geographic Information System (GIS), Multi-Criteria Decision Analysis (MCDA), and the Analytical Hierarchy Process (AHP), among others. The researchers proposed the Strategic Urban Development Decision Framework (SSUDDF), which streamlines key criteria and processes specific to strategic urban innovation, such as those of the City of Ekurhuleni (CoE) (Mashiri, Njenga, Njenga, Chakwizira & Friedrich, 2017). However, despite municipal smart governance initiatives (Ncamphalala & Vyas-Doorgapersad, 2019), challenges, including but not limited to infrastructure, unemployment, poor governance, and finances, confront and hinder the CoE from achieving smart city status. Such challenges can be solved through the adoption of modern-day innovative solutions provided within a smart city concept (Ncamphalala & Vyas-Doorgapersad, 2019). This notion not only transforms economic efficiency but also delivers to citizens improved, effective, and accelerated public service (Westraadt, Calitz & Cullen, 2019). As noted by Mabaso (2018), for the realisation of smart city status, a city requires enhanced utilisation of digital technologies to improve performance, reduce costs, and engage its citizens effectively and actively.

A recent study by Arnardu and Francke (2021) of the City of Cape Town showed how the Cape Town government initiated and progressed through the processes to attain its smart city status. The researchers (Arnardu & Francke, 2021) proposed a framework combining two frameworks: the Nokia taxonomy of smart city applications and the principles of the Smart Africa Manifesto, as an attempt to apply triangulation across theory, data sources, and data collection methods. The study conducted interviews with key stakeholders, such as City of Cape Town ICT officials and the Western Cape government, on whom the adoption of the smart city concept depends. Moreover, critical questions central to the stakeholders' discussions were adapted from the principles of the Manifesto, which provided the following highly anticipated insights that led to transforming the city into a smart city (Arnardu & Francke, 2021):

a. The City of Cape Town socioeconomic development agenda embraces,
b. enhances access to ICT and broadband infrastructure,
c. improves accountability, efficiency, and openness through ICT via the connected strategy that broadens citizen participation in the economy,
d. adopts a private sector business-friendly approach, provides expertise and enterprise development, and
e. leverages ICT to promote and collaborate with key stakeholders to market Cape Town as an African ICT hub and competitive destination.

Accordingly, the city gained insights into smart city advancements from the Shanghai smart city in China (Arnardu & Francke, 2021) by observing developments such as the large internet-enabled local market that has swiftly arisen, integrated payment systems that revolutionise how business activities are carried out (Mokoena *et al*., 2017), residents' daily accessibility of internet, application developers' open data exchange platforms, smart parking to ease congestion, and an initiative known as Citizen Cloud, among others.

In the opinion of Adeniran, Shakantu, and Ayesu-Koranteng (2022), waste management is a must-have service that exists across all societies. However, waste still occupies a significant portion of the landscape. With their diverse waste management policies, South African municipalities, particularly metropolitan municipalities, have shown significant initiative in combating this scourge (Khwene, 2020). Consequently, the objectives of the policy documents are out of sync with waste management in practice, which continues to pose a tremendous risk to human and environmental health (Sharma *et al*., 2020; Viljoen, Schenck, Volschenk, Blaauw & Grobler, 2021; Koen & Fourie, 2022). Ijemaru, Ang, and Seng (2022) argue that waste management cannot be carried out effectively, transparently, or efficiently without adequate data collection and management systems. Adeniran et al. (2022) proposed implementing a digital participatory waste management service monitoring system (DPWMS) to enhance the city's waste management services and optimise user relationships. The system features a mobile app, Unstructured Supplementary Service Data (USSD), short message service (SMS), and an accompanying website to store, evaluate, and disseminate information provided by residents (Adeniran *et al*., 2022). As part of the system, citizens are expected to send a photo from their mobile devices or via USSD/SMS to a digital platform that receives and processes their images (Ijemaru *et al*., 2022), which then sends them to a drone at the identified location, as shown in the image. As the drone surveys the areas, the municipality's waste management worker or service provider will perform the required tasks while monitoring the drone's imagery and providing feedback to the resident (Adeniran *et al*., 2022; Ijemaru *et al*., 2022). It enables municipalities in South Africa to address or provide smart solutions to one of six critical environmental challenges associated with smart cities; it can also be modified to address other crucial issues, such as water, traffic, and health management (Adeniran *et al*., 2022).

Various municipalities in South Africa have realised that ICTs play a role in their development and have begun planning and investing in recent technologies. However, issues such as inadequate infrastructure, electricity generation capacity, and governance concerns, among others, continue to be challenges. In addition, municipalities' limited resources are a barrier to achieving significant developments or projects in becoming a smart city. In this sense, cities in developing countries with financial constraints are unlikely to rank highly in well-known international indexes. Financial restrictions can abbreviate the incentives to implement intelligent initiatives in those countries. According to the literature, a city's smartness is not only about technical issues but also about using available resources effectively and involving society in the provision of solutions.

Overall, the implementation of smart city frameworks in South Africa is still in the early stages, and massive investments in ICT infrastructure and human capital development are necessary. Like developed economies, South African municipalities have also developed bold, smart city plans that are part of government policy aimed at improving citizens' quality of life and competitiveness.

Throughout the texts mentioned earlier, the concept of innovative initiatives and/or solutions has been discussed to utilise a variety of smart technologies and to advance the development of new industries or enhance stakeholder interaction in a city (Karuri-Sebina & Guya, 2020). The authors mention many kinds of ingenious creativity. These examples encompass all six main components, their implementation, intended benefits, and the discourses they align with, as shown in Table 2.8.

Table 2.9: Common Smart Initiatives and the Discourses they Reflect, adapted from Karuri-Sebina and Guya (2020)

Initiative	Intended benefits	Example	Discourse
Smart Economy			
Incubators and *hubs*	The creation of new jobs contributes to economic growth	Among South Africa's innovation hubs are *Innovate Durban, Tshimologong*, and The *Innovation Hub.*	Economic growth, Human development
Building *new cities* to be smart	Cities that are smarter and more competitive	The *Lanseria Junction* smart city is being proposed for Gauteng (Plessis & Wood, 2021).	Economic growth, Human development
Online *procurement* processes	Trustworthy government procurement	As a result of the *Gauteng Open Tender* system, irregular expenditure in the province has been reduced.	Economic growth, Service delivery
Smart Mobility			
Traffic monitoring and *management*	Better traffic flow, safer driving	A traffic management model can be used to alert drivers of congestion and alternative routes (Mbodila, Obeten & Bassey, 2015).	Technology, Service delivery
Improved *public transport*	Reduced emissions, improved air quality, shortened transit times, and reduced congestion by private vehicles	An app called *GoMetro Public Transport* provides information on buses and trains from five South African transport providers.	Service delivery, Human development, Environment
Shared transport, including cars and bikes	Fun and excitement, fewer vehicles, and optimal use of vehicles	In 2018, Tshwane and the University of Pretoria tested a *shared bike pilot project*, but the area's dense traffic and lack of cycle lanes limited its implementation.	Environment, Human development
Smart Environment			

Initiative	Intended benefits	Example	Discourse
Smart meters	Better data for decision-making and reduced costs.	Johannesburg City Power implemented smart electricity meters (Xulu, 2013).	Technology, Service delivery
Sensor networks to monitor *water use*	Accurate response for maintenance, lower costs for improved public service	Smart water meter data was collected to explore household responses during the Cape Town water crisis. (Booysen *et al.*, 2019).	Technology, Environment
Waste management using apps	Higher volumes of recycling, improved livelihoods for information waste collectors	To reduce carbon emissions and use landfill sites, eThekwini has developed a *waste-to-energy* project.	Environment, Economic growth
Smart People			
Using *social media*	Faster communication, better understanding of stakeholder views	X is a social media platform used by Joburg Water and City Power to provide citizens with information and updates about their services.	Service delivery, Technology
Consultation processes to engage with city stakeholders	Greater engagement, policies, and solutions benefit from collaborative design	*My Ekurhuleni* is an app designed to facilitate communication between residents and the municipality.	Human development, Service delivery
Smart Living			
Camera and personal *surveillance* with machine learning techniques	People feel safer, understanding criminal behaviour, and reducing crime	By providing emergency services through a single toll-free number, the Public Emergency Communication Centre aims to make Cape Town safer.	Technology, Human development
Public *internet access* through wi-fi, network rollouts	Increase skills, improve access, address inequality	Backhouse and Chauke (2020) argue that free public Wi-Fi in Johannesburg has improved residents' economic standing.	Human development
Smart Governance			
Using established *information systems* like ERP, CRM, and financial systems	Efficient processing of large volumes of data, consistent processes, and accuracy	In the early 2000s, the City of Cape Town employed an ERP system to integrate its business processes, which underpin its digital transportation strategy (Boyle & Staines, 2019).	Service delivery
City *websites* for information and online service provision	Increased access to city services, improved ease of doing business	*e-Tshwane* is a website provided by the Cities of Tshwane and Ekurhuleni that gives access to the cities' range of electronic services and updates on the municipalities.	Service delivery, Economic growth
Electronic voting and polling systems	Frequent polls on more issues, greater accuracy, and increased voter turnout	The South African government elections at all levels are managed fairly by the *IEC*.	Human Development, Technology

Several studies have shown that lessons learned from smart cities can be used to improve historically marginalised or disadvantaged areas (Antwi-Afari *et al.*, 2021). Moreover, research by Akanbi (2025) suggests that partnerships between city officials and researchers can foster more integrated efforts and enable cross-city learning by bringing together institutions within and across levels of government.

2.7 Conceptual Frameworks Approach

Frameworks are tools required not only for assessing the appropriateness of research problems and questions, but also for ordering and operationalising the research design (Masenya & Ngulube, 2019). Similarly, conceptual frameworks are analytical tools that organise work in a unified way, differentiate concepts, describe the state of knowledge, identify knowledge gaps, and outline the methodology of a research project (Ullah, 2021). Regarding this, smart city frameworks are designed to accommodate IoT architectures as the backbone within municipal structures and to establish the various components that make up and impact these architectures (Zhang, Babar, Tariq, Jan, Menon, & Li, 2020).

As a result of Industry 4.0 (Majid *et al*., 2022), great opportunities are offered for sustainable development to be realised (Makieła *et al*., 2022), and this has a direct effect on manufacturing, leading to the creation of a conceptual framework for Industry 4.0 readiness assessment tools (Demong *et al*., 2021). Based on Keyes (1998), this framework measures an organisation's Industry 4.0 readiness across five components: social integration, social acceptance, social contribution, social actualisation, and social coherence, as depicted in Figure 2.4. A review of a variety of existing social well-being perspectives and models in industry and academia related to Industry 4.0 readiness was helpful, aided by this framework (Demong *et al*., 2021).

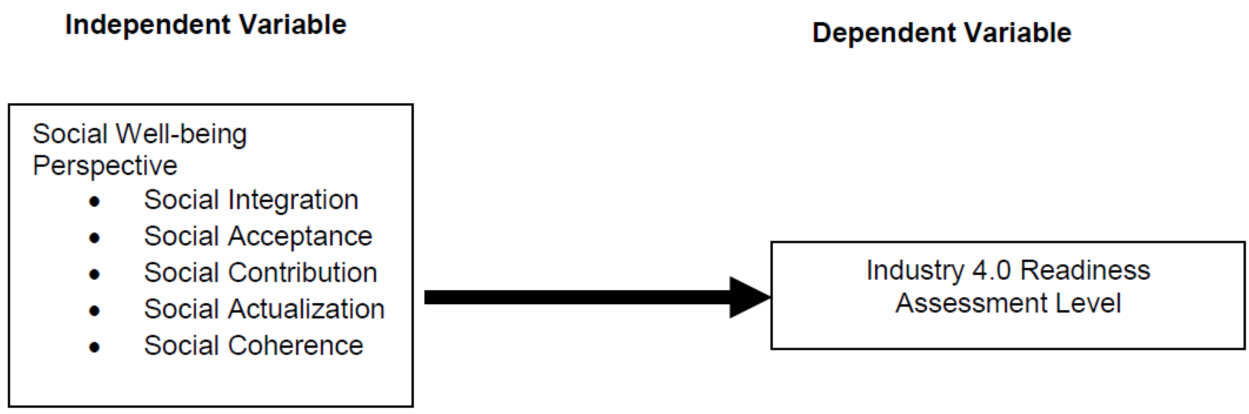

Figure 2.4: Conceptual Framework for Industry 4.0 Readiness Assessment Tool based on Social Well-being perspective (Demong *et al*., 2021)

The measurement of organisation readiness level is classified into five components of the social well-being perspective (Demong *et al*., 2021):

- **social integration** - an overwhelming feeling of belonging to a community, which brings comfort and support;
- **social acceptance** - respecting the differences of others whilst recognising the positive aspects of each;
- **social contribution** - the sense that one's life and work are valuable to others and beneficial to society;
- **social actualisation** - having faith in the potential of individuals, groups, and societies to develop or grow, and
- **social coherence** - a desire to know about society or social life; a feeling that society and culture can be understood, sorted out, predictable, and meaningful.

OALF is an Overarching Autonomous Learning Framework developed by Muthaiyah and Zaw (2021) that includes distinct layers, namely Acquisition, Data, Business, and Application architectures that make a city smart, with an emphasis on Business Architecture having autonomy and self-learning capabilities. According to Muthaiyah and Zaw (2021), smart capabilities need to be able to reason and act independently with very little or no human involvement (Ding, Jin, Li & Feng, 2021); thus, to be deemed smart, a device or system must be capable of thinking independently under challenging situations. Two technologies, IoT and artificial intelligence (AI), made this possible (Muthaiyah & Zaw, 2021). This framework is used to measure interest in promoting the assessment of social well-being, along with psychological and emotional well-being, among others.

In developing a conceptual framework for competitive smart city spatial performance, Kourtit (2021) identified critical success factors (CSFs) based on measurable KPIs for reliable assessment. A city-scale analysis of macro- and meso-KPIs primarily assesses external urban conditions. In contrast, location-based geoscience analysis is generally used for spatially detailed analysis of the internal functional factors. With this framework, it is possible to assess the liveability conditions of districts, neighbourhoods, or even individual streets in modern cities (Sabory *et al.*, 2021) to obtain a detailed picture of sustainable, healthy, and safe urban environments, as well as achievements related to health, safety, cohesion, and governance (Kourtit, 2021).

Hamzah, Adnan, Daud, Alias, and Dali (2016) developed the Reconciled Smart City Assessment Framework (RSCAF), composed of two main parts that connect to conceptual variations of the smart city: Resilience Smart City (RSC) and Smart Resilience City (SRC). The former is created as a mixture of parts that connect conceptual variations of the smart city, and the latter is designed as a vital baseline tool to measure the city's ideal and actual smartness across its main functions throughout the assessment exercise shown in Figure 2.5 (Hamzah *et al.*, 2016). To estimate a city's smartness performance, a wide range of indicators for each domain is grouped into sets, and each key field is calculated from the aggregated indicator values within each domain (Moustaka *et al.*, 2021). Moreover, the RSCA framework is incorporated to enforce further and improve the validity of the proposed framework. In essence, the already available theory provides the starting point for the framework development; it asserts that assessment of a city's smartness should be based on (1) six imperative smart city domains; (2) the unique main functions of the specific city; (3) the planned smart initiatives; (4) actual requirements of the city stakeholders and, subsequently, smart initiatives of the inhabitants (Hamzah *et al.*, 2016). These frameworks serve as step-by-step guidelines to indicate whether a city is resilient or innovative. Further analysis and investigation by Tzioutziou and Xenidis (2021) concluded that resilience and smart city frameworks share fundamental determinants, enabling the development of a unified concept rather than two distinct approaches in the context of urban development. Meanwhile, the concept of urban resilience can be seen as serving the goal of sustainability and has a similar operational framework as that of smart cities (Benites & Simoes, 2021); in terms of operationalising resilience, the smart city model appears to be instrumental given the importance of the technological dimension (Tzioutziou & Xenidis, 2021; Khatibi *et al.*, 2021). According to the findings, resilience thinking serves as the theoretical background, whilst smart city solutions constitute the design requirements, highlighting the specific roles of the two concepts within the emerging integrated framework (Tzioutziou & Xenidis, 2021).

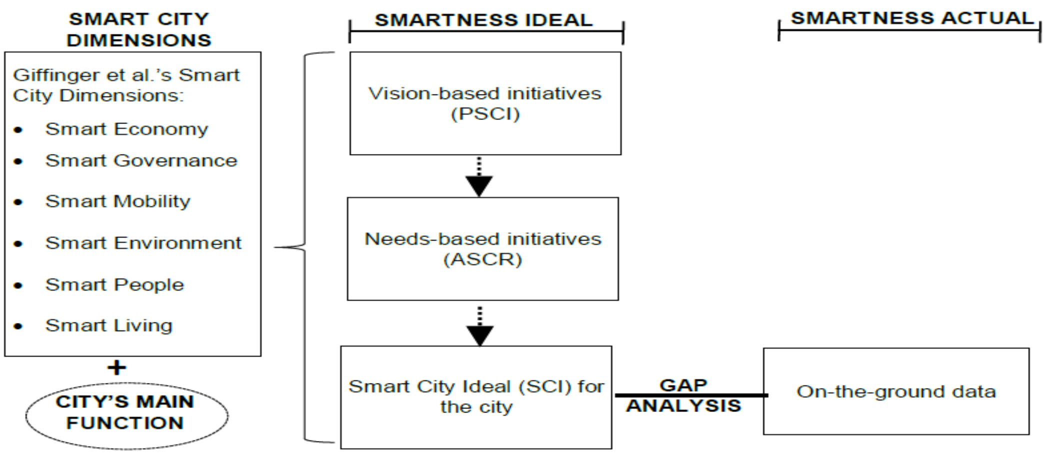

Figure 2.5: The Reconciled Smart City Assessment Framework (RSCAF), adopted from Hamzah *et al.* (2016)

2.8 Framework for Smart Cities within South African Municipalities

Fundamentally, South African municipalities require clear guidance on how to adopt, implement, and utilise smart and digital futures (Das, 2020). Key to a successful implementation of clear guidance is to employ available frameworks from both local and international arenas that adhere to the legislation, policies, and strategies that regulate components that make a city smart (Balkaran, 2019; Ullah, Al-Turjman, Mostarda & Gagliardi, 2020). Successful development of a smart city requires the inclusion of private, semi-public, and public actors and the encouragement of cooperation between them (Xydis, Pagliaricci, Paužaitė, Grinis, Sallai, Bakonyi & Vician, 2021). Furthermore, an analysis of internal factors, such as policies, strategies, current systems, and architecture (Das, 2020), as well as external factors, such as political, socio-economic, technological, and environmental factors, positively influences the development of smart city frameworks within the context of the target setting of local government. Accordingly, for a smart city to succeed, it must have a systemic, reliable, flexible, and resilient policy framework; a critical monitoring of policy outcomes in uncertain times; and a goal-oriented transparency (Kourtit, 2021). Keshavarzi *et al*. (2021) assert that in a smart city, technology does indeed play an important role; nevertheless, not all the services are technology-based; cities can adopt and enforce new policies and new initiatives to enhance their urban quality of life, address their negative externalities, and enhance performance by combining technology advancements and non-technological options.

A growing body of literature indicates the existence of frameworks that can be adopted, combined, adapted, and extended for South African cases. It is, however, not uncommon for frameworks to be comprehensive; hence, many studies undertake efforts to integrate theories to meet the needs of a particular city. For example: (1) a combination of Geographic Information System (GIS), Multi-Criteria Decision Analysis (MCDA), and Analytical Hierarchy Process (AHP) to develop a Strategic Urban Development Decision Framework (SSUDDF); and (2) Nokia taxonomy of smart city applications and the principles of the Smart Africa Manifesto frameworks by Mokoena and Sebola (2020), Khatibi *et al*. (2021), and Arnardu and Francke (2021).

2.9 Waste Management and Reporting Systems

The Matjhabeng Municipality in the Free State province of South Africa, amongst others, faces the challenge of effectively managing and reporting on uncollected solid waste. The ineffective management and reporting of waste subsequently compromise public health and safety

(Amugsi, Muindi & Mberu, 2022). Waste can be defined as any solid substance transported, dissolved, or suspended in water, or disposed of on land, that can cause pollution of surrounding areas (Nyika, Onyari, Mishra & Dinka, 2020a). Waste is usually generated because of daily human activities (Adeniran *et al*., 2022). The generation and management of waste are essential challenges for developing towns and cities worldwide. The Department of Environmental Affairs estimates that 90% of waste generated in South Africa ends up in landfills and illegal dumpsites, while 10% of the disposed garbage is recycled (Siwawa, 2025). Many municipalities face challenges of illicit dumping and overflowing waste bins, and are responsible for removing waste to maintain a clean and healthy environment; Matjhabeng Municipality is not immune to this. Poor solid waste management results in various unfavourable impacts, such as lake contamination, the spread of disease to animals, and risk to human health (Lidia, Julio, Petra & Rafael, 2018). While waste pick-ups are often carried out according to a specific weekly schedule, collection is sometimes missed or delayed, necessitating on-demand alternative methods (Dada, Faniran, Ojo & Taiwo, 2023).

Recent work by Li, Lee, and Lau (2023) established a five-step waste hierarchy to prioritize waste prevention, presented in Figure 2.6.

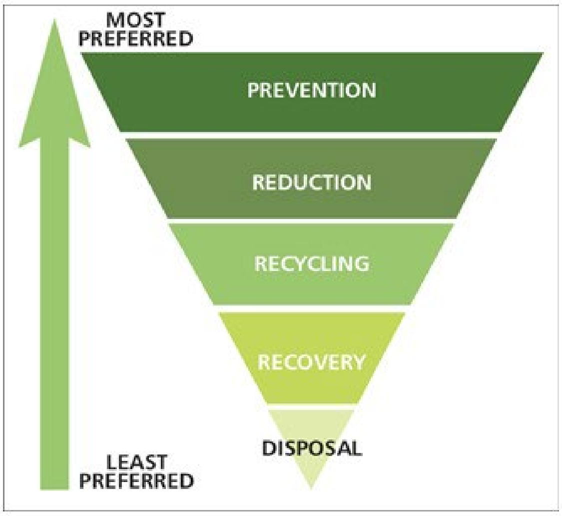

Figure 2.6: Waste Management Hierarchy adopted from Li, Lee, and Lau (2023)

The IoT enables waste segregation techniques to develop systems to separate distinct types of waste, enhance the efficiency of waste collection, and emphasise recycling processes (Nwokediegwu *et al*., 2024). Besides, using mobile applications allows waste generators and producers to request waste collection services, enables municipalities to manage waste effectively, and reduces waste generation (Singh, Dikshit & Kumar, 2024). More importantly, Nyika, Onyari, Mishra, and Dinka (2020b) argue that, under the National Waste Management Strategy (NMWS), municipalities promote a trend towards waste minimisation, reuse, and recycling in recognition of these difficulties. Therefore, waste should be collected and disposed of in designated garbage bins to minimise the negative impact of unattended waste on pollution (Ahen & Amankwah-Amoah, 2021). Furthermore, guidelines are in place that assist the municipality in enhancing waste removal services, improving waste management processes, and ensuring that waste is disposed of at designated garbage bins, such as using waste bin sensors, as noted by Ghahramani, Zhou, Molter, and Pilla (2022).

Community involvement in waste reporting through mobile applications facilitates and emphasises the identification of waste hotspots (Nwokediegwu *et al*., 2024). Among other factors identified by Kasat, Shaikh, Rayabharapu, Nayak, and Sayyad (2023), a centralised platform is required to support monitoring of data collection for analysis; furthermore, an effective mobile app should allow users to rate municipal services more efficiently after waste collection. Moreover, introducing mobile applications helps users with real-time updates on collection schedules and disposal points, and encourages sustainable waste management practices (Henrys, 2021).

2.10 An Introduction to Machine Learning

Over the last two decades, machine learning has grown exponentially into a cornerstone of Industry 4.0 and smart manufacturing (Qin & Chiang, 2019). Interestingly, the advent of advanced sensors, high-performance IoT devices, cloud computing, and greater data volume has led to increased use of AI and machine learning, as noted by Ullah *et al.* (2020). The capabilities of AI technology are predominant in shaping the modern world today and can emulate countless automated actions that would typically be performed and controlled by humans (Cascu, 2025). Moreover, machine learning is an integral part of AI, involving the development of algorithms that learn from data and make predictions or decisions without explicit programming instructions (Cascu, 2025). Data characteristics and algorithms play a significant role in determining the effectiveness and efficiency of machine learning solutions. Pawlik, Wilk-Jakubowski, Frej, and Wilk-Jakubowski (2025). Maintain that machine learning algorithms can process large amounts of data rapidly and accurately, while conventional interventions may prove challenging when learning about individuals, business processes, transactions, and events. Machine learning solutions are generally more effective and efficient when the data and algorithms are well-chosen and of high quality (Sarker, 2021).

2.10.1 Machine Learning Types

In addressing shallow methods, deep learning, as further expressed by Apruzzese *et al*. (2023), often requires more computing power and larger datasets, and machine learning algorithms can be classified as supervised or unsupervised and rely on reinforcement learning. Hussain, Hussain, Hassan, and Hossain (2020) and Sarker (2021) provide summaries of the four main types of machine learning, presented in Table 2.9.

Table 2.10: Descriptions of Three Different Types of Machine Learning, adapted from Hussain *et al.* (2020) and Sarker (2021)

Learning	Description
Supervised	Using supervised learning, you can predict the value of an outcome measure from input measures (Hastie, Tibshirani, Friedman, & Friedman, 2017). Supervised learning is divided into two types, namely regression and classification.
Unsupervised	Unlike supervised learning, unsupervised learning lacks a set of outcomes to measure; instead, the goal is to identify patterns and associations among inputs (Hastie *et al*., 2017). Different types of unsupervised learning problems are clustering and association.
Semi-supervised	As a hybrid of supervised and unsupervised learning, semi-supervised learning operates on both labelled and unlabelled data, balancing the strengths of both.
Reinforcement	It can be a valuable tool for solving complex problems, but it is not a good tool for solving fundamental or straightforward ones. Generally, this algorithm can be divided into two types, namely model-based and model-free.

2.10.2 Machine Learning Applications

The application of machine learning to real-life problems has become a focus of computer scientists in recent years. Alymani, Almoqhem, Alabdulwahab, Alghamdi, Alshahrani, and Raza (2025) further note that the positive societal effects of machine learning and IoT have received significant attention from academics and industry in recent years. For instance, to estimate the transmission effect of innovation, Zhu, Zhang, Wang, Li, Yang, Song, Zhao, Huang, Shi, Lu, Niu, Zhan, Ma, Wang, Xu, Wu, Gao, and Tan (2020) used machine learning. A study by Qin, Hu, Liu, Witherell, Wang, Rosen, Simpson, Lu, and Tang (2022) also found that machine learning technologies have demonstrated effectiveness across industries such as computer science, aviation, healthcare, and manufacturing. Corporate management currently uses machine learning methods to optimize production processes (Li *et al*., 2019). According to Qin *et al*.'s (2022) study, a data-driven approach based on machine learning technologies has become increasingly common in digital manufacturing systems for discovering hidden knowledge and building highly complex relationships. The success of the study towards Industry 4.0 was the integration of additive manufacturing into digital systems and sensor networks that facilitate the collection of large volumes of data.

Using a machine learning model trained on historical network data, Pawlik *et al.* (2025) argue that the model should be capable of optimising networks intelligently, analysing data, and automating the provision of network services. The choice of a suitable model, however, should be based on a proper understanding of the problems involved (Singh, Pujar, Kumar, Bhagyalalitha, Akshatha, Abuhaija, Alsoud, Abualigah, Beeraka & Gandomi, 2022). In other words, a problem should be clearly defined; appropriate and relevant data should be collected; an artificial intelligence model architecture should be designed; a model should be trained, evaluated, and the output should be correctly interpreted (Singh *et al.*, 2022). While integrating multiple data sources can be a challenge for many software systems, this data can be analysed quickly using machine learning and AI (Li *et al.*, 2019). Similarly, according to the study by Qin *et al.* (2022), machine learning models trained on reliable datasets uncovered hidden patterns and latent knowledge to improve processes, quality control, and systems. Thus, Din *et al.*'s (2019) study found that in IoT and machine learning, tiny devices generate data, which applications analyse, enabling communication, sensing, data collection, and information analysis. They furthermore argue that by using these applications, IoT systems gain sophisticated insights and ideas that can be used to modify and enhance services. This view corroborates the ideas of Singh, Jeong, and Park (2020), who state that a key requirement in developing IoT-oriented infrastructure-related smart applications is data interoperability, and this becomes even more complex when it comes to combining data from a wide variety of devices and service areas, such as IoT and other networks.

Moreover, machine learning is gaining popularity because of its ability to learn from the past and make intelligent decisions in the Fourth Industrial Revolution (Sarker, 2021). In Sarker's (2021) book, ten popular applications of machine learning technology are identified and described; however, this study singles out just a few:

- *Predictive analytics and intelligent decision-making* refer to the ability to accurately predict the future to improve decision-making in both public and private sectors, including, for example, industries, businesses, and almost any organisation, such as the government, e-commerce, telecom, banking and financial services, healthcare, sales and marketing, transportation, and social networking, among others (Sarker, 2021).

- *Cybersecurity and threat intelligence* are the practices of protecting networks, systems, hardware, and data from digital attacks. For instance, through data analysis and machine learning, it can identify patterns, detect malware in encrypted traffic more effectively, identify insider threats, predict problematic neighbourhoods online, keep people safe while browsing, and secure data in the cloud by revealing suspicious activity.
- *Healthcare and the COVID-19 pandemic* entail various medical domains that can benefit from machine learning at the diagnostic and prognostic levels. For example, scientists can use machine learning to predict where and when COVID-19 might spread, enabling appropriate preparations in those regions.
- *E-commerce and product recommendations* are some of the most prominent features of almost every e-commerce website today. For instance, it is common for online retailers to use machine learning-based predictive modelling to manage inventory more effectively, prevent out-of-stock situations, and optimise logistics.
- *Traffic prediction and transportation,* as traffic volumes increase in several cities around the world, transport systems have become a crucial component of economic development. Consequently, modern society suffers from delays, traffic congestion, higher fuel costs, increased air pollution, accidents, and the need for emergency services. The machine learning model can, for example, be used to predict potential issues along specific routes based on travel history and transportation trends along those routes.

2.11 Detailed critical literature analysis

The global frameworks for smart city development and the implementation of the Internet of Things (IoT) provide valuable guidelines. However, significant gaps arise when applied to South African municipalities. Many frameworks emphasize advanced infrastructure, reliable connectivity, and robust data management systems (Javed *et al*., 2022), including the International Organization for Standardization (ISO) standard ISO 37122, which provides indicators for smart cities, as well as the Smart Sustainable Cities standard. In general, like other African countries, South African municipalities face infrastructure, financial, and capacity constraints that limit their ability to implement these frameworks directly (Das, 2020). Additionally, smartness is not measured using a localised system of measurement in several areas, including service delivery efficiency, informal settlement integration, and digital inclusion. In this context, while global frameworks are applicable overarching principles, they must be adapted to reflect local socioeconomic realities, governance structures, and technological advancements.

Furthermore, most of the innovative municipal initiatives currently being implemented in South Africa, particularly in waste management and citizen reporting, are conventional projects instead of scalable, data-driven ecosystems (Adeniran *et al.*, 2022). There are many potential benefits to IoT-enabled waste management systems and mobile applications for service reporting. However, these systems often require expertise in development, implementation, and integration with centralized municipal databases and analytical platforms. Machine learning algorithms, among others, could be used to enhance real-time decision-making and predictive maintenance, which are hindered by fragmentation (Pawlik *et al.*, 2025). One of the key gaps is the development of an integrated framework tailored to the needs of South African municipalities that incorporates IoT technologies, establishes data governance protocols, ensures interoperability among systems, and leverages machine learning to identify patterns and optimize resource use. Among others, inadequate infrastructure, insufficient electricity generation capacity, and governance concerns continue to pose challenges. Addressing these gaps would enable municipalities to transition from responsive service-delivery models to proactive, intelligent urban management systems that improve quality of life.

2.12 Summary

This chapter comprised the literature review and was informed by the research objectives. The literature reviewed included theses and dissertations, books, journal articles, and conference proceedings. The work done in this chapter so far includes understanding the concept of smart cities through a review of history and prospects, and providing definitions of smart cities and the possible factors that influence their performance, such as IoTs and digital and technological infrastructure. Also, theoretical frameworks implemented both globally and in South Africa were deliberated upon. Likewise, the machine learning definition, including its history and principles, was briefly reviewed in the literature, followed by a discussion of waste management and reporting systems implemented strategically by several municipalities, both locally and abroad. Also, in this chapter, the RSCAF theory served as the underpinning theory. The next chapter details the methodology employed in this research.

CHAPTER THREE – RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

According to the literature, science is informed by a careful, disciplined, and logical search for knowledge, and this chapter presents the research methodology used in this study to determine the most appropriate research approach. An explanation of the chosen research paradigm is given at the beginning of the chapter. As shown in Figure 3.1, a research map summarizes the research methodology and design diagrammatically. In addition to the research design, a description of the research approach is provided. This chapter discusses the data collection techniques used, followed by the analysis and presentation of the data. A discussion of sampling methods and ethical considerations is also provided. This chapter provides a rationale for the procedures and methodologies used to collect and analyse the data presented.

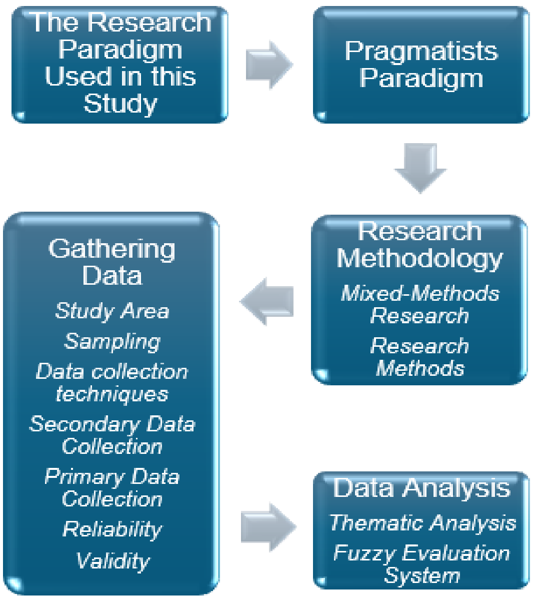

Figure 3.1: Research Map Summarising the Research Design and Methodology (Author)

3.2 The Research Paradigm Used in this Study

This study draws on the ontologies and epistemologies of the two paradigms studied, as well as the research purpose, to develop an assessment framework for evaluating the understudied municipality in South Africa, which considers pragmatism as a suitable research paradigm. This choice helped the researcher to discover and understand the world (Matjhabeng) through the in-depth insights, perceptions, systems, processes, and perspectives of the participants, including the municipal officials.

As a fusion of positivist and interpretivist methodologies, pragmatism encompasses both perspectives. Considering the above discussion, this research study has opted for a pragmatic paradigm and a mixed-methods sequential exploratory design.

3.3 Pragmatist Paradigm

According to pragmatism, practical solutions are always offered to address problems that are suitable to existing circumstances; they engage with social, historical, political, and other contexts or situations (Cresswell, Anderson, Montgomery, Weir, Atter & Williams, 2023). Pragmatism rejects the idea of a single objective reality, as it aims to answer both the 'what' and the 'how' of a question, which is relevant to the aim of this study (Sol & Heng, 2022). The researcher used mixed-methods research as a philosophical perspective, drawing on both qualitative and quantitative assumptions when conducting the research, focusing on the research problem under study, and applying a wide range of methods to both understand and develop the framework. As such, the research problem was at the forefront, and all available approaches, including data collection and analysis, were used to address the research objectives. Accordingly, since pragmatic worldviews lead to mixed-methods research, the investigator was free to choose a sequential exploratory research design as the method best suited to the project. Therefore, to effectively address the study problem statement, the sequential exploratory approach was a perfect choice, given its ability to address research problems qualitatively and quantitatively. The underlying concept behind opting for this paradigm is through its ability to acknowledge each approach's weaknesses and therefore compensate for them.

3.4 Research Methodology

Many different research methodologies can be applied to any research problem, and each has its relative strengths and weaknesses; no single methodology is necessarily ideal, so selecting one always involves both gains and losses (Nayak & Singh, 2021). Three factors influence the selection of research methodology: the paradigm that guides the research activity or the theory of knowledge that informs the research, known as epistemology; the method by which it can be acquired, identified as methodology; and the beliefs about the nature of reality and humanity, known as ontology, according to Nayak and Singh (2021).

This study adopts a pragmatist perspective, as mentioned earlier, and mixed-methods research is associated with pragmatism. Several key characteristics of the methodology described above, along with a justification for the methods employed in this research, will be discussed in the following sections.

3.4.1 Mixed-Methods Research

Research involving mixed methods includes a set of processes and designs that integrate qualitative and quantitative approaches to address research questions or to obtain insights into the phenomena under investigation (Fàbregues, Hong, Escalante-Barrios, Guetterman, Meneses, & Fetters, 2020). For this reason, this method was a better choice, as the nature of this study involved and required a blend of these two approaches. The qualitative data were collected before the quantitative data. Thus, through a mixed-methods study, municipal officials' perspectives on daily operations and challenges were explored and drawn through a qualitative component of this methodology. Quantitative data were used to measure the framework produced from the qualitative data. The details of the element of mixed research methods are presented and analysed in the following sections.

3.4.2 Research Methods

According to Cresswell *et al*. (2023), a mixed-methods design enables researchers to employ various strategies. The duo identified five qualitative research designs: case studies, phenomenology, grounded theory, ethnography, and narratives, as well as two quantitative research approaches: experiments and surveys.

To guide this study, both case studies and surveys were used. This design's strength in collecting data from various sources and culminating in a case description and its thematic elements made it the desired choice.

Rowley (2002) presents a helpful classification system based on the quantity of cases and the number of units within each case; see Table 3.1 below:

Table 3.1: Case Study Designs, quoted from Rowley (2002)

	Single-case designs	**Multiple-case designs**
Holistic (single unit of analysis)	Type 1	Type 3
Embedded (multiple units of analysis)	Type 2	Type 4

A single-case study can function as a pilot test for multiple-case studies, as Rowley (2002) notes. One case may consist of only one unit of analysis (holistic single-case design) or several units of analysis (embedded single-case design). There are two types of multiple-case study designs: holistic (with a single unit of analysis) and embedded (with multiple units of analysis) (Rowley, 2002).

This study employs an exploratory sequential design (qualitative and quantitative) and focuses on the entire Matjhabeng Municipality as a case study. Figure 3.3, seen in section 3.5.3 of this Chapter, provides valuable information on the sequential use of qualitative and quantitative methods in the case study. Also, sample sizes varied by study focus: five participants were interviewed, while quantitatively, both municipal IDP and StatsSA data sources were used. The interviews were held at the municipality's official offices for convenience and cost-effectiveness. This study adopted the type 2 embedded single-case study design presented in Table 3.1 since the focus is on one municipality.

3.5 Gathering Data

Detailed descriptions of each data collection method will be provided in the following subsections.

3.5.1 Study Area

As highlighted earlier, the study utilises the Matjhabeng Local Municipality as its primary case study. Situated in the Lejweleputswa District Municipality within the Free State province, Matjhabeng Local Municipality is depicted in Figure 3.2. It shares boundaries with the Nala Local Municipality to the north, Masilonyana Local Municipality to the south, Tswelopele Local Municipality to the east, and Moqhaka Local Municipality to the west. It serves as the focal point for mining activities in the Free State province. Like other municipalities across South Africa, this municipality plays a pivotal role in service delivery, bearing primary responsibilities such as providing and maintaining essential services for its communities. These services encompass water utilities, municipal roads, stormwater management, solid waste collection, electricity provision, firefighting services, and more (Cooper *et al*., 2025).

Figure 3.2: Matjhabeng Local Municipality Map in South Africa, Free State Province (Source: Republic of South Africa, 2023)

3.5.2 Sampling

When selecting targeted subjects for this study, thoughtful consideration was given to choosing the most relevant and impactful individuals, thereby ensuring the collection of the most comprehensive and impactful data. As highlighted by Adeoye-Olatunde and Olenik (2021), sampling is a crucial element of any research design and significantly impacts the reliability of study outcomes. The credibility of study findings depends heavily on participants' understanding of the subject matter. For this reason, the targeted population comprised directors from distinct directorates from which the researcher sought to gather data.

To select participants, the researcher used interview guide questions drawn from the IDP, along with input from managers across different municipal structures. The selection was neither the researcher's nor the manager's choice, but was determined by the collection of questions relevant to different municipal directorates. Hence, the need to be careful not to elevate the risk of bias and subjectivity was overcome.

This study opted for a purposive nonprobability sampling design because it is cost-effective, convenient, and time-efficient, and it is ideal for an exploratory research design. Since sampling in qualitative research is subjective, the chosen method is considered appropriate for this study. The selection of the study sample was not based on a specific number of respondents but instead on the breadth of questions and their significance, identified through document analysis, along with crucial input from the manager responsible for the municipal organogram.

This collaborative process ultimately determined the sample size for the comprehensive interviews.

A total of five participants remained an optimal representative number for the initial phase of this exploratory sequential study. When choosing potential respondents, demographic factors such as age, gender, ethnicity, and race were not considered. The selection process prioritised merit, ensuring that respondents could offer crucial and distinctive insights primarily from a directorate perspective. Detailed information could not be obtained by merely utilising data collection tools, such as a questionnaire, which would not enable the researcher to ask follow-up questions that seek to acquire relevant information required for the study

3.5.3 Data Collection Techniques

A description of the data collection techniques that were used for gathering data is presented and justified in this section. As shown in Figure 3.3, the data collection methods used in this study can be visualised. For this research study, document analysis of municipal IDP and StatsSA documents was used as a data collection method. As part of phase one, qualitative data collection was conducted through the acquisition, examination, and analysis of a Matjhabeng legal blueprint document (IDP), the first step in the case study. Based on this data, an interview guide was developed, interviews were conducted, and thematic analyses were conducted to generate insights for developing the SAF framework. The final step involved creating a system prototype of a mobile application for waste management and reporting. During phase two, the study evaluated the SAF framework developed during phase one using the StatsSA dataset. The fuzzy synthetic evaluation (FSE) method was used to calculate the smartness index for the municipality, and the results were then presented. As this research study proceeds, subsequent subsections will elaborate on the secondary and primary data collection techniques used.

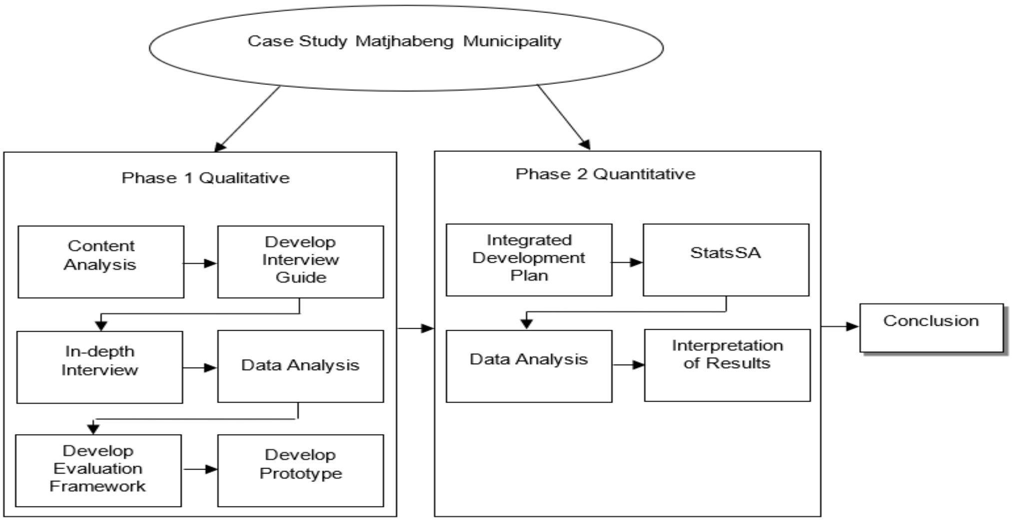

Figure 3.3: Implementation of Exploratory Sequential Design, adapted from Hamamurad, Jusoh, and Ujang (2022)

3.5.4 Secondary Data Collection

This refers to historical data from other sources or secondary research that has been previously collected and documented. For example, historical data is collected from sources such as textbooks, journal articles, state government documents, private data services, computer databases, and development plans, among others.

3.5.4.1 Document Review

As part of qualitative data collection, a thorough examination and analysis of the municipal IDP aided in realising the key authorities' duties in providing services to their communities. These services incorporated, amongst others, water utilities, municipal roads, stormwater management, solid waste collection, electricity, firefighting services, and other essential amenities, as outlined in various texts and policy documents. In this municipality, as in many others, critical decision-making rests with elected councillors, while appointed municipal officials and staff execute the municipality's daily administration tasks.

In this context, scrutiny was directed towards city development plans, legislative instruments, and statutes to gauge their influence on and regulation of service delivery planning and development. The review proved instrumental in creating an interview guide, which was used to gather qualitative data from relevant directorate officials in the Matjhabeng Local Municipality.

The initial steps in this process involved seeking permission to conduct the study at Matjhabeng Local Municipality through discussions with an official. Following their advice, the researcher and their supervisor engaged in a dialogue and decided to formalise the request by composing a letter addressed to the municipal manager's office. The drafted letter (see Appendix B) was then finalised and submitted to the office of the municipal manager. However, obtaining approval was a protracted process that required persistent follow-ups.

After several months of waiting, the municipal manager's office finally responded with a letter granting permission for the research to proceed. The office of the municipal manager stipulated that any necessary study information should be sought from the municipal office's suitable structures. Nevertheless, gaining access to official or confidential municipal documents posed challenges due to established procedures. To establish legitimacy, the permission letter was presented at the initial meeting with the structures manager as evidence that permission had been granted to conduct the research.

At the structural manager's offices, access to documents required confirmation from the municipal manager's office. Therefore, access to the digital documents was granted based on the obtained confirmation. Subsequently, for several weeks, if not months, thorough examination, analysis, and engagement of content were undertaken while taking detailed notes. This groundbreaking information paved the way in shaping the development of questions that later formed the basis of the interview guide (see Appendix A). An illustrative example of the letter issued by the Municipality of Matjhabeng, serving as evidence that the study had obtained permission to access information from local authorities for research purposes, is provided in Appendix C.

3.5.4.2 Statistics South Africa

Study framework findings were obtained using a structured quantitative dataset retrieved from StatsSA as part of the secondary data collection. Importantly, StatsSA is the only entity responsible for producing official statistics in South Africa. It collects and compiles data on a diverse range of topics, such as people, economies, living conditions, and the natural environment, using sources such as censuses, surveys, and administrative data, and provides interactive access to the data. Therefore, the StatsSA census dataset for 2023 was used, as it provides complete, accurate, and representative information for the Matjhabeng Local Municipality. Among the essential elements of this dataset were total population, gender, population groups, age groups, school attendance, highest level of education, type of dwelling, access to piped water, toilets, and refuse disposal, as well as energy for lighting and cooking. As a result, these elements were crucial in assessing the framework and evaluating the study.

3.5.5 Primary Data Collection

In primary data collection, the researcher gathers immediate information from the field. It is usually raw data that must be processed and analysed. Observations, interviews, focus group discussions, field surveys, or questionnaires may all be used to collect data (Pandey & Pandey, 2015). In this study, primary data were collected through in-depth interviews.

3.5.5.1 Interview

The interview was carried out by the researcher using an interview guide format developed in this study, which is structured with questions that probe the smart governance, economy, people, living, environment, and mobility aspects of the municipality, and the remaining part of this interview can be found in Appendix A. Careful planning was undertaken for individual interviews with key officials, thorough preparations were made, and a suitable environment was arranged before commencement. Participants interviewed engaged in interactive discussions, with assurance that they understood the study purpose and felt welcome. Notably, before each interview commenced, the interviewer requested permission from district officials to record the proceedings. This practice saved time compared to taking detailed notes during the interviews. The recordings for all five interviews were kept on both the recorder and a backup on the researcher's password-protected laptop until all the interviews were concluded.

Furthermore, participants' privacy and confidentiality concerns, as well as informed consent, were considered before the interviews. This was a precaution employed to ensure that participants' confidentiality was valued and protected.

Data were collected over six months, from September 2023 to March 2024, and detailed interviews were conducted, including with five key officials from Matjhabeng Local Municipality. Each interview lasted approximately 70 minutes. Importantly, interviews were cost-effective, as no time or resources were spent on travel, as most were conducted on the municipality's premises. Exceptions were made where interviews were conducted in places deemed convenient for the participants. Participants were contacted and invited to participate in the study before the interviews. The preparations involved providing participants with various information about the topic and purpose of the study, as well as the major questions they would need to answer. Before the session, information from the research preface was also shared.

3.5.6 Reliability

Sürücü and Maslakci (2020) define reliability as the ability to predict the outcome of a similar study with similar respondents and within similar contexts. As an alternative explanation, the outcomes might have been the same if a different individual had conducted the research. A reliable study reduces error in the results by ensuring that the collected data falls within the scope of the research questions (Aithal & Aithal, 2020). According to Warneke, Gronwald, Wallot, Magno, Hillebrecht, and Wirth (2025), reliability is difficult to measure because respondents may change their opinions over time, fail to recall their previous answers, or even intentionally change their views. A larger sample size also enhances the consistency of results by reducing the likelihood of extreme responses and increasing variability, resulting in more reliable data (Sürücü & Maslakci, 2020). An examination of one's own judgments, practices, and belief systems during the data collection process was identified by Aithal and Aithal (2020) as a method to enhance confidence in the validity of the research results. Therefore, according to Singh (2017), it is recommended that researchers furnish detailed methodological accounts to clarify the path to specific conclusions. Nonetheless, to avoid common errors researchers often make in translating developed instruments, all interviews were conducted in English, and the same language was used in the written document, as noted by Sürücü and Maslakci (2020).

Throughout this study, reliability was diligently maintained across its various phases. To enhance reliability, clear, explicit language was used during interactions with respondents, ensuring they understood and interpreted questions accurately and provided suitable responses. Additionally, the interview guide underwent refinement through pre-testing sessions with the supervisor. Each question was carefully examined, and critical feedback from the supervisor was incorporated, leading to adjustments such as excluding questions, rephrasing, and rewording specific questions.

3.5.7 Validity

Validity pertains to the extent to which a measurement instrument accurately reflects what is occurring in the target population or real-life scenarios, based on the precision of data obtained from the sample (Warneke *et al*., 2025). It is through validity that researchers ensure the data presented reflects the issues investigated. Validity is broadly categorised into two measures: internal and external validity (Singh, 2017; Sürücü & Maslakci, 2020). However, these measures can be further subclassified, including catalytic, consequential, face, content, construct, convergent, discriminant, criterion-related, concurrency, predictive, and ecological validity (Singh, 2017; Sürücü & Maslakci, 2020).

Internal validity concerns the accuracy of the results within a specific research project and the demonstration of cause-and-effect relationships (Aithal & Aithal, 2020). For instance, in a questionnaire, if a respondent selects multiple options or ticks more than one box for a question, it undermines internal validity (Warneke *et al*., 2025). Similarly, in interviews, the absence of a tracking system for participants increases the likelihood of losing track of each participant's responses (Roulston, 2011).

On the other hand, external validity concerns the generalisability of research findings from the subjects under investigation to other situations or contexts (Singh, 2017). As mentioned in the research methods section 3.4.2 of this Chapter, one drawback of a case study is its limited sample size, which restricts the extent to which results can be extrapolated or generalised to other situations, thereby limiting external validity.

Sürücü and Maslakci (2020) contended that collecting diverse types of valid evidence is essential and advocated the accumulation of multiple sources. Building upon this notion, Du, Peng, and Pinfield (2017) asserted that employing mixed methods is preferable to single-method approaches, as it mitigates bias and enhances data validity. Motivated by this rationale, this study adopted a mixed-methods research design that integrated qualitative and quantitative data collection methods. To ensure the study's validity, two distinct approaches, face validity and content validity, were used to assess the accuracy of the collected data (Singh, 2017).

Face validity serves as a measure to assess the scientific integrity and relevance of the researcher's chosen measures (Aithal & Aithal, 2020). This approach aligns with the recommendation of Aithal and Aithal (2020) to involve expert judges to enhance the face validity of measures in this case, municipal officials. This argument challenges the limitation of face validity, emphasising that its drawback lies in its subjective nature. Consequently, what one researcher may find convincing may not be persuasive to others, leading it to be viewed as a less robust form of structural validity (Sürücü & Maslakci, 2020).

Content validity pertains to whether the researcher comprehensively measures all relevant aspects and concepts under study. For instance, interview questions must effectively explore the study's intended topics, while questionnaires should accurately assess the targeted areas (Sürücü & Maslakci, 2020). As with facial validity, the researcher evaluated the content validity of the interview guide through ongoing consultations with the supervisor and other professionals, including experts in municipal structures, to address aspects such as the clarity and relevance of the interview questions (Sürücü & Maslakci, 2020).

The study bolstered triangulation through a mixed-methods approach, examining the problem from various perspectives to fortify the validity of the findings. To achieve this, data were collected from multiple sources (Aithal & Aithal, 2020), including in-depth interviews with selected municipal officials and archival data from the IDP policy document. This was complemented by a StatsSA survey that provided insight into citizens' lived experiences in the Matjhabeng municipal area regarding the provision of basic services.

3.6 Data Analysis

Following qualitative data collection, the researcher analysed the gathered information. The recorded data were transcribed, a standard method for converting audio recordings into written text for research purposes. The transcribed data then underwent a thematic analysis process aimed at establishing connections within the data to enhance understanding for others and contribute valuable insights to research. Furthermore, the quantitative data collected from StatsSA were used to evaluate the SAF framework at work and were statistically analysed using the FSE method.

3.6.1 Thematic Analysis

Thematic analysis is regarded as a rigorous and inductive process designed to identify and examine themes from word-based data in a way that is transparent and dependable (Batra, 2021). Since the data collected from interviews was qualitative, the researcher did not have much of a structure for it to be analysed, and thematic analysis was carried out following the stages presented in Figure 3.1:

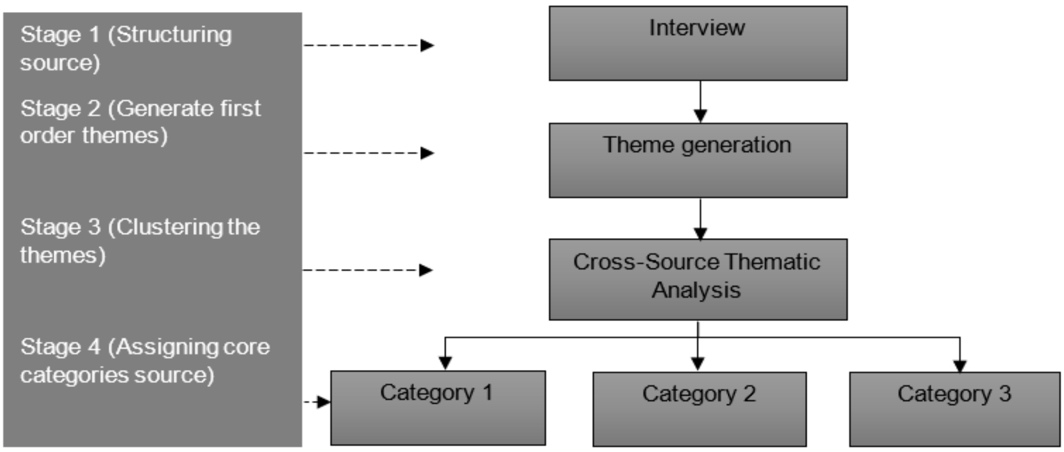

Figure 3.4: Thematic Analysis Method, adapted from Batra (2021)

The thematic analysis consists of four stages, as depicted in Figure 3.1. Stage 1 starts with the structuring and classification of data sources. Stage 2 of the thematic analysis involves generating individual themes, also known as first-order themes. Stage 3 presents the cluster analysis and cross-source analysis leading to the clustering of the themes. Stage 4 presents the assignment of core categories using NVivo 14. This computer-assisted Qualitative Data Analysis Software (CAQDAS) was used to code and analyse all the information provided by the participants in the study.

a) Stage 1: Structuring the source

The study employed qualitative research to collect primary data. Interviews were conducted with five participants, all of whom held certain positions in different directorates of Matjhabeng Local Municipality. The interview guide consisted of various questions for different directorates, and this classification provided the flexibility to code, interpret, and draw connections among the sources. An adaptive research approach was used to provide a comprehensive perspective on smart city implementation within this municipality.

b) Stage 2: Individual theme generation

The interview data contributed significantly to the generation of the generated themes, giving informed insights about prevalent themes as follows: (1) Encourage students to pursue alternative career opportunities; (2) Collaborate with SETAs (Sector Education and Training Authorities) on skills development in communities; (3) Collaborate with local businesses; (4) Introduce advanced technology; (5) Partner with higher learning institutions; and (6) Examine regulatory compliance for public transport, amongst others. Through coding the interview data, 105 themes were identified. It was possible to systematically validate the four-tier approach by generating themes at the individual level and assessing them holistically across multiple data sources.

c) Stage 3: Clustering of the themes

As each theme was generated, the correlations and patterns between them were explored. Organising many themes into groups simplified the analysis and systematically handled the complexity. As a result, the themes were grouped based on their relationships, associations, and fundamental nature as seen in Chapter 4.

d) Stage 4: Assigning core categories

During this stage, all previous steps were closely scrutinised to ensure the core categories presented here accurately represented the assigned themes for the data analysis. A final set of six major themes or categories was developed, which captured the essence of the clusters of themes and their relationships, and this study draws inspiration from them. They are:

1) Initiatives taken to incorporate youth in economic development and decision-making;
2) Operational strategies for resource management and staff optimisation;
3) Challenges;
4) Actions taken to implement changes in a municipality;
5) Impact of proposed strategies on municipal governance and community functioning, and
6) Municipality action plans for sustainable innovation and social development.

3.6.2 Fuzzy Synthetic Evaluation (FSE)

In FSE, fuzzy terms are represented and manipulated using degrees of membership rather than strict true-or-false membership. The study relied on FSE for its well-known quantitative capabilities that can efficiently capture diverse information from many sources, allowing an analysis of complex problems (Wu & Zhang, 2021). A qualitative data analysis using FSE was conducted to examine the SAF framework's findings further. As most of the quantitative data came from StatsSA, percentages helped describe and present the data.

In this study, the quantitative nature of the data used to evaluate smartness led to choosing FSE over inferential statistics, as it can handle uncertainty without requiring assumptions, particularly in contrast to inferential statistics. The tool also provides a more realistic and comprehensive data presentation as it can handle multiple datasets through membership functions. To conclude, FSE not only accommodates overlapping and uncertain data but also produces analyses that are flexible, understandable, and predictable in real-world situations, unlike inferential statistics methods that rely heavily on approaches that seek to understand the relationships between independent and dependent variables based on prior assumptions about the data structure, as noted by Fountzilas, Pearce, Baysal, Chakraborty, and Tsimberidou (2025).

3.7 Ethical Clearance for Empirical Research

At the Central University of Technology, Free State, the Department of Information Technology, the Departmental Research and Innovation Committee, and the Faculty Research and Innovation Committee approved the research study. Then it enabled the researcher to commence fieldwork.

Research should always be bound by high ethical standards (Brittain, Ibbett, de Lange, Dorward, Hoyte, Marino, Milner-Gulland, Newth, Rakotonarivo, Veríssimo & Lewis, 2020). The ethical considerations of any study are crucial, as no one should be disadvantaged by the knowledge derived from it when researchers seek answers to specific questions about the phenomenon under investigation.

As part of the consent letter, participants were invited to participate in the research in a face-to-face meeting. Before the interview, participants were informed of the interview process, the type of data to be collected, and the time commitment required of them. In addition, the letter included a firm guarantee that participants could withdraw from the interview at any time.

3.8 Summary

This chapter outlined pragmatist research as a paradigm adopted in this study. The research follows a mixed-methods approach, combining qualitative and quantitative methods to provide a holistic understanding of smart city smartness. A variety of research methods employed in this study were discussed. Data collection techniques were carefully examined to capture the true essence of the research process. The data analysis component elaborated on the use of thematic analysis, a qualitative method for identifying patterns and themes. At the same time, FSE was discussed quantitatively as a method for assessing and ranking smartness indicators with greater precision. Notably, the chapter highlighted that the study adhered to all necessary ethical protocols, including obtaining ethical clearance from the university to conduct research responsibly and thereby respecting participants' rights and confidentiality.

Chapter 4 focuses on detailed data analysis and framework development.

CHAPTER FOUR – DATA ANALYSIS AND FRAMEWORK DEVELOPMENT

4.1 Introduction

This chapter presents and discusses the results of the qualitative data analysis that informs the framework. Using five key participant interviews, as explained in the previous chapter, qualitative data were collected and analysed thematically. This chapter commences with Figure 4.1, which presents the findings from the data analysis, and then elaborates on them. It focuses on detailed data analysis and framework development.

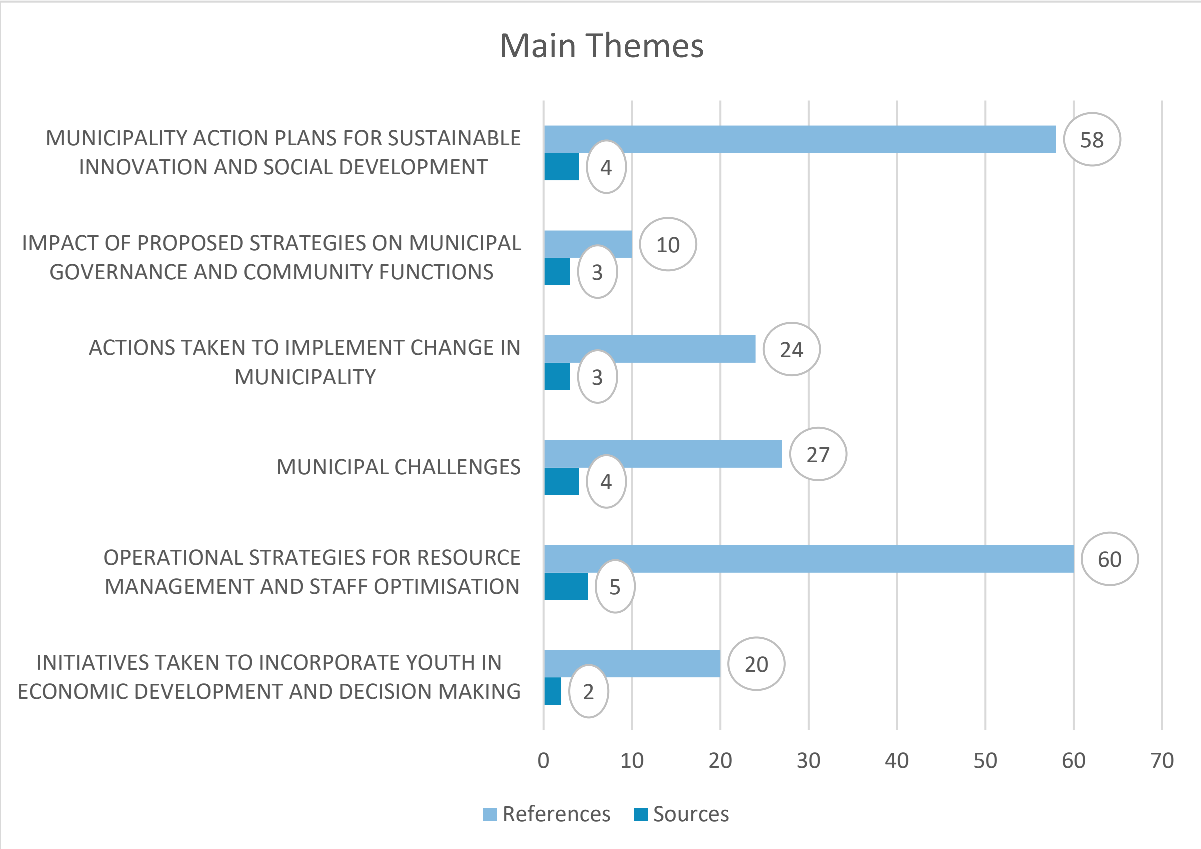

Figure 4.1: Thematic Analysis Themes (Author)

The primary themes identified during the data analysis are presented in Figure 4.1. These visual aids illustrate the main themes and their sources: participants who contributed to the study, and references indicate the amount of data each participant provided for each theme. The theme of operational strategies for resource management and staff optimisation received the most discussion, involving all five participants and generating 60 references. The impact of board size on decision-making in municipal action plans for sustainable innovation and social development ranked second among themes, with 58 references. It was followed by municipal challenges and actions taken to implement changes in a municipality, which garnered 27 and 24 references, respectively. Initiatives to incorporate youth into economic development and decision-making had 20 references. In contrast, the theme of the impact of proposed strategies on municipal governance and community functions had the fewest insights, with only 10 references.

Furthermore, Table 4.1 presents 74 raw indicators derived from thematic data analysis. This table shows the indicators derived from the six themes shown in Figure 4.1.

Table 4.1: Domains, Sub-domains, and Indicators from the Analysed Data

Domains	Sub-domains	Indicators from Data Analysis
Smart Governance	Finance	1. SETA's budget limits support for basic job skills 2. Facilitates the payment process 3. The ICT infrastructure is used to control and promote the payment remotely of services by the users
	Government	1. Offer regular training to stay up to date with technological advancements 2. Directors must complete the CMPD performance certification 3. Introduction of advanced technology 4. Modernised operations through better data management **Challenges identified include:** 1. The absence of short workshop programs 2. Employees do not complete programs initiated to empower them 3. Impact of training programmes not evident 4. Insufficient training provided to empower municipality employees 5. Lack of monitoring systems on the development programs implemented 6. Lack of business management skills 7. Lack of administrative oversight 8. Political interference negatively impacts the work environment 9. Staff lack relevant qualifications 10. Poor investment in saturated skills 11. Poor investments in vacant buildings 12. Poor performance on audits despite interventions 13. Poorly drafted reports 14. Limited support for technical skills
	Telecommunication	1. Alignment of municipal policies and ICT 2. ICT systems to ensure connectivity functionality 3. Fibre connectivity must be reliable 4. Security challenges that accompany the increasing connectivity
	Urban planning	1. Draw up a five-year master plan 2. Ensure alignment of planning documents with IDP 3. Partner with experts to implement initiatives 4. Establish a regulatory framework aligning with government laws 5. Ensure the plan is based on feasibility studies and passes the reliability test 6. Train HR on labour and disciplinary practices
Smart Economy	Economy	1. Encourage students to pursue alternative career opportunities 2. Partnered with Tumbaga Foundation and CUT to empower employees with technical skills development 3. Exposure to different operational systems and strategies in entrepreneurism 4. Host roadshows to disseminate information 5. Provide a platform to share fundable ideas 6. Offer support to small businesses 7. Received sponsorship to empower students or employees 8. Revive and refurbish the warehouse to accommodate young entrepreneurs 9. Empower students through these programs to prepare them for labour market 10. Authorise legislation to ensure data privacy 11. Engage with investors to implement initiatives 12. Small-scale mining solutions and alternative industry development 13. Research and collaborative solutions for municipal problem-solving 14. Centres to support research and development initiatives
Smart People	Education	1. Offering good salary packages 2. Modernising training colleges 3. Support self-development and provide bursaries

Domains	Sub-domains	Indicators from Data Analysis
		4. Collaborations with SETAs to provide skills development in communities 5. Investment in professions that enhance employability and entrepreneurship prospects 6. Skills Levy Act ensures annual staff training 7. Partner with higher learning institutions 8. Availability of bursaries for students
	Urban/local agriculture and food security	1. Organise skills seminars for emerging farmers 2. Equip the youth with entrepreneurial skills in agriculture
Smart Living	Health	1. Improved access to healthcare facilities by expanding service hours, staff employment
	Housing	1. The municipality has embarked on Smart Meters for both electricity and water
	Population and social conditions	1. Assess the underprivileged and ensure strict conditions to receive services 2. Widespread access to mobile devices, internet connectivity
	Safety and security	1. Draft a safety security plan 2. Primarily focus on ensuring security and safety
	Sports and culture	1. The municipality supports sports, games, and cultural festivals 2. Libraries need maintenance
Smart Environment	Energy	1. Property repurposing in collaboration with the municipality 2. Gas technologies as solutions underway 3. Provision and installation of street lighting
	Environment and climate change	1. Budget allocation for maintenance plans 2. The buildings have become health hazards
	Solid waste	1. Potential solutions to reduce waste 2. Plans to explore the use of waste-to-energy are underway as a potential solutions
	Wastewater	1. Budget for sewer networks and wastewater treatment works
	Water	1. Provision of clean drinking water 2. The municipality has embarked on Smart Meters for water
Smart Mobility	Transportation	1. Test the reliability of internet availability concerning transport networks 2. Integrated transport plan to improve efficiency and effectiveness 3. e-Hailing for lower carbon emissions and road congestion 4. Examining regulatory compliance for public transport 5. Technological infrastructure necessary for successful implementation

This is the first version of the analysed data table, divided into domains, sub-domains, and indicators. Taking the analysis process a step further resulted in a detailed matching and correlation of six themes, presented in Figure 4.1, derived from *data analysis* of smart city Domains, as well as the definition of their respective *Sub-domains* in Table 4.1. Lastly, indicators from the data analysis were assigned to their respective sub-domains in the third column titled *Indicators from Data Analysis*. It is worth noting that during indicator grouping, indicators were identified that intersected with other themes, even though they were grouped according to the six key smart city domains. The indicators belonging to the same domain were grouped, and sub-domains were created. This process was carried out and organised manually. The first set of indicators was set up to meet the requirements of the smart governance domain and its related sub-domains. A second set of indicators was set up based on the requirements of the smart economy domain and its sub-domains. Based on the smart people domain and its sub-domains, the third group of indicators was developed. Indicators focused on smart living and its relevant sub-domains were placed in the fourth group. The fifth set of indicators was determined based on the smart environment domain and sub-domains therein. Finally, the final set of indicators was chosen to address the smart mobility domain and its associated sub-domains. This table influenced the development of Table 4.2, which is considered the second version of this one.

4.2 A Framework for the Successful Assessment of Smartness for Municipalities

To understand how the smartness of a municipality can be assessed, Antwi-Afari *et al*. (2021) note a considerable lack of guidance on devising or implementing frameworks tailored to address the evolving needs of smartness assessment tools. To address this gap, a practical framework for measuring a municipality's smartness is proposed. As mentioned earlier, this framework draws inspiration from the Reconciled Smart City Assessment (RSCA) model by Hamzah *et al*. (2016). The RSCA model employs six domains to compare ideal smartness with actual smartness, pinpointing areas where conventional municipalities may require support. It underscores the interdependence and mutual benefit among various domains and administrative processes within the municipality. This framework is centred on the recognition of a pressing need to evaluate municipal performance in terms of service delivery to the community. In essence, the framework serves as a navigational tool for a municipality to progress efficiently within a dynamic environment and attain and sustain essential competencies.

4.3 The Objective and Intent of the Framework

Since the fundamental goal of developing an assessment framework for the municipality is to systematically evaluate the performance of its environment, capturing the complexity of its operational systems by considering the multiple factors that influence these systems and the diverse functions they encompass is critical. The Matjhabeng SAF emerged from synthesising various components, criteria, and KPIs used in existing frameworks that assess either the municipality's "smartness" (Inac & Oztemel, 2021) or the effectiveness of specific aspects of service delivery operations. According to Khatibi *et al*. (2022), resilient smart city governance incorporates strategies that help make municipalities smarter. An integrated framework that incorporates smart city principles is crucial for enhancing municipal efficiency and developing strategies to address municipal challenges. This approach encourages the municipality to be productive and motivated to provide better, higher-quality services to citizens. The framework builds upon existing municipal development systems rather than replacing them, thereby enriching their capabilities. The framework draws from the following frameworks: 1) RSCA, discussed earlier in the literature review section 2.7 of Chapter 2, which introduces a distinct model characterised by unique perspectives, features, and dynamics identified by municipal experts during the interviews. 2) ESC, this model provided a foundation for most smart city approaches that followed, hence SAF was no exception; its domains were considered and incorporated into the development of SAF as discussed in section 2.5 of Chapter 2, respectively, with some level of control by a municipality. It will later be assessed over a specific period using an innovative waste management and reporting system, with objectives tracked throughout the evaluation period. The assessment will be ongoing and follow a predetermined schedule.

Although each municipality has its unique characteristics, it remains the researcher's responsibility to ensure that the framework evaluation aligns with the specific needs of the given municipality, in this case, the Matjhabeng Local Municipality. The following diagram in Figure 4.1 illustrates the framework.

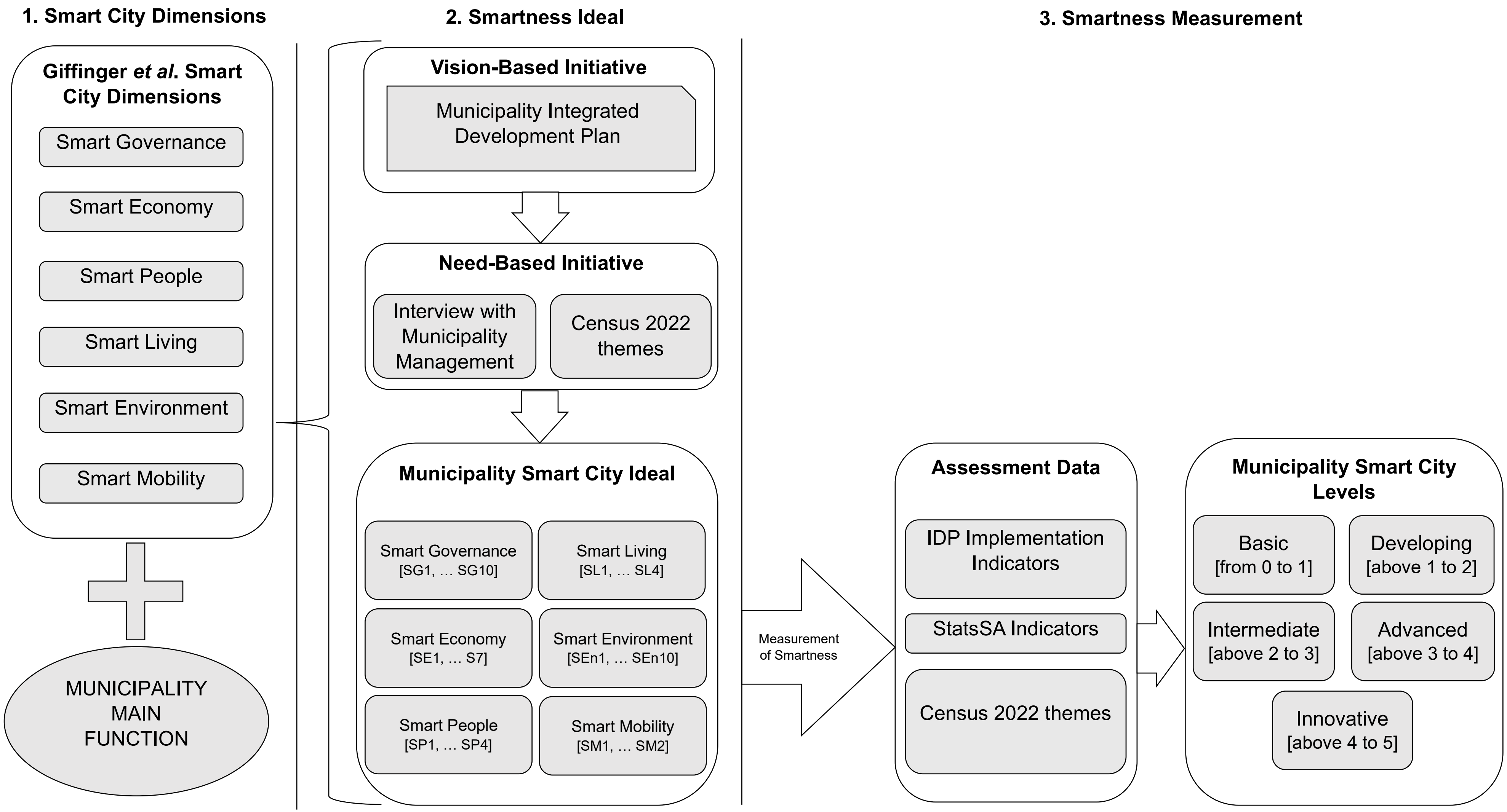

Figure 4.2: Matjhabeng Municipality Smartness Assessment Framework (Author)

4.4 The Main Structure and Interconnected Elements

The subsequent section outlines the discussion for each component of the framework.

4.4.1 Layer 1: The Smart City Domains

The layer encompasses the six conventional domains of a smart city: smart governance, smart economy, smart people, smart living, smart environment, and smart mobility. In addition, the layer includes the municipality's primary function. A municipality can have multiple functions encompassing political, economic, and social goals; demography; level of technology; administrative structure; environment, geography, and socio-political conditions. The components are presented as they were identified in the literature review chapter.

4.4.2 Layer 2: The Smartness Ideal

This layer, as shown in Figure 4.2, comprises three critical components: a vision-based initiative, a need-based initiative, and the municipality's smart city ideal. These components are explained in detail below.

4.4.2.1 Vision-Based Initiative

Municipalities typically develop statutory development plans that provide visionary goals. The statutory development plan lists the policies and programs expected to be implemented to achieve the organisational vision. Planning initiatives, regardless of their form, are elements of municipal smartness evident in development plans, policies, or programmes. This study uses IDP as a guiding tool to achieve the municipality's vision-based initiative and enhance its level of smartness. An IDP serves as a comprehensive blueprint for a municipality's development. Per Section 25 of the Local Government: Municipal Systems Act 32 of 2000, every municipal council is required to adopt an IDP every five years to achieve its expanded constitutional mandate at the onset of its elected term. The Act establishes the responsibilities of political officeholders, municipal officials, and the community. It also examines human resources and public administration while advocating for citizen engagement throughout to promote a participatory government system. Equally, the plan is designed to be singular, inclusive, and strategic, and to incorporate the municipality's development aspirations. Its significance lies in harmonising various plans, incorporating development proposals, and aligning the municipal resources and capabilities with the plan implementation.

More importantly, for municipalities, as Pollio (2020) notes, the IDP is the primary legally prescribed governance instrument. Its specific focus is on undoing the stratification and fragmentation embedded in apartheid spatial planning. Many city visions include smart city concepts in IDPs. Buffalo City Metropolitan Municipality (BCMM), for example, aimed to be a well-governed city: an effective and efficient municipality providing high-quality services (Scholtz & van der Hoogen, 2022). This project aims to establish a smart city concept for the city (Scholtz & van der Hoogen, 2022). Likewise, although the Ekurhuleni IDP states that it aims to be a smart, creative, and developmental city (Ncamphalala & Vyas-Doorgapersad, 2022), it offers little insight into how it will achieve this objective. Furthermore, in Johannesburg, the vision is more developed, and their strategic priority includes:

- Smart City and Innovation, which seeks to offer internet access in learning communities;
- Smart meters, e-services, widespread broadband access, and general service efficiency;
- Enhance safety and mobility through the integration of city-wide data, allowing for holistic planning, preventative actions, and improved responses;
- Provide technology and connectivity to businesses and entrepreneurs, increasing economic activity, and
- Lastly, engage citizens in active citizenship via a Joburg App (Foster, 2020).

Besides, legislation orders engagement with communities for collaborative decision-making in civil administration. For this reason, municipalities are required to clearly define five-year IDPs to progress administration through coordination and vital, medium-term planning (Ranchod, 2020).

Hence, in the Matjhabeng development plan, the detailed data outlined for the schemes, policies, and community programmes were studied, analysed, and implemented as part of the assessment criteria for measuring the municipality's smartness level. Thereafter, the analysed data laid the groundwork for the development of qualitative data collection instrument questions, known as an interview guide.

4.4.2.2 Need-Based Initiative

In a need-based initiative, support is provided to individuals or groups whose needs are identified by a community, organisation, or group. It is therefore essential to implement a new municipal development plan in line with the needs of those involved. Residents and workers are the municipality’s primary stakeholders, as they represent many of its users and the groups most likely to be affected by its development measures. To determine the effectiveness of management functions, a general assessment should be conducted through data collection from stakeholders using qualitative and/or quantitative methods. To assess the effectiveness of management functions, stakeholders should participate in a data-collection process that may include both qualitative and quantitative approaches.

a) Interview with Municipality Management

As previously stated, part of the need-based approach includes conducting five comprehensive interviews with essential officials in Matjhabeng Local Municipality who had been appointed as directors for several directorates. In summary, municipal administration is made up of the following critical structure, as shown in Table 4.2 (IDP, 2023):

> *"This table highlights the following important management positions: The Municipal Manager appointed by Council in terms of Section 82 of the Municipal Structures Act, 117 of 1998, and is designated as the accounting officer, administrative head, and Chief Information Officer of the municipality, and is responsible for managing the Promotion of Access to Information Act, 2 of 2000 requirements. The Municipal Manager's responsibilities include managing financial affairs and delivering services within the municipality. The Municipal Manager is assisted by the Executive Directors, who head seven municipal departments. The municipality has structured its departments so that each has an Executive Director appointed under Section 56 of the Municipal Systems Act, 32 of 2000, for its core functions. Alignment of these functions is such that they enable a swift attainment of all our strategic and operational targets."*

Table 4.2: Municipal Structure, adapted from IDP (2023)

Position
Municipal Manager
Chief Financial Officer
Executive Director – Strategic Support Services
Executive Director – Corporate Services
Executive Director – Infrastructure
Executive Director – Local Economic Development
Executive Director – Human Settlement
Executive Director – Community Services

The table above clearly shows the key positions governing the municipality in order of appearance, starting with the municipal manager and ending with the executive director of community services. It is the responsibility of executives appointed to these positions to oversee every critical aspect of the municipality. As a result, crucial information and the authorities vested in these positions are vital to implementing a clean, transparent government and making informed decisions about this municipality. Likewise, information obtained from executives assigned to these positions is considered extremely valuable and significant to the growth of this study, as it captures the municipality's key tasks. Thus, the interviews with five directors were conducted with the authorisation of the municipal manager, who also serves as the municipal accountant. Accordingly, part of the preparation process included presenting participants with a wide range of information regarding the study topic and objectives, as well as the primary questions they would be asked. Before each session started, information regarding the study introduction was presented. Similarly, giving participants enough time to answer questions throughout the interview allowed the interviewer to listen actively. This method made it easier to probe for clarification on ambiguous comments, allowing respondents to provide additional insights on municipal procedures relevant to this study.

b) Census 2022 Themes

Data was collected from the municipal officials through face-to-face interviews. Generally, StatsSA data is quite comprehensive, covering a complete set of information on issues affecting South African citizens. Hence, the StatsSA data were obtained from relevant sources, consisting of themes that most closely met the requirements for the information sought to support the study's intended needs. These Census 2022 Themes, released in October 2023, included several key themes, including population characteristics, basic service access, and immigration patterns. Equally importantly, this data included demographic trends, education levels, and disability prevalence. Furthermore, the Census provided data on the number of households, type of dwellings, access to piped water, sewerage infrastructure, refuse disposal, and different uses and sources of energy in South Africa. The census data is used against the six-dimensional municipal smart city ideals of the study framework; the framework has varying numbers of indicators, ranging from two to ten, to measure each dimension. This census is used to quantitatively measure the indicators for each dimension discussed in the next section to determine the smartness performance level of Matjhabeng Local Municipality.

4.4.2.3 Municipality Smart City Ideal

Based on the need-based initiatives, distinct, measurable indicators were identified for each of the six domains of the municipality's smart city ideal, as presented in Figure 4.1. From this, indicators in the study were selected based on the following criteria: (1) objectivity, such as clear, easy to understand, precise, and unambiguous; (2) relevance, measurability, and reproducibility, including quantitatively and systematically observable; (3) validity with the possibility of verification and data quality control; (4) representativeness at the municipal level; (5) comparability over time; and (6) accessibility through available databases and use of existing data. These indicators, which were informed by the data analysis, reflect the comprehensive configuration of smart city initiatives that the municipality should possess to achieve a level of smartness that meets its primary functions. One of the most balanced and well-integrated standards for municipal smartness elements is addressed through the indicators, as supported by D'Amico *et al*. (2020). As indicated earlier, the choice of indicators is closely related to achieving the desirable goals of smart cities, which are organized into six domains: Smart Governance, Smart Economy, Smart People, Smart Living, Smart Environment, and Smart Mobility. Equally importantly, the ISO's smart city indicators are compared to the study's final, further analysed and refined indicators (presented in Table 4.1), and a few examples of how the indicators match and relate to each other are highlighted after this table. As an international organisation that sets standards for the development of smart cities, the Smart City ISO is vital to guiding municipalities towards smartness, not only because of its global reputation but also because municipalities are embracing the standards (Klassen, 2025). Therefore, the study adopted ISO standards to ensure that the indicators used in the proposed framework are of high quality and meet the necessary standards for measuring municipal smartness. Furthermore, Table 4.3 shows the *indicator code* names derived from the domain and subdomain abbreviations, along with the indicator number. For example, Smart Governance (SG) Finance (F) indicator number 1 (IND1) is shown as SG1. Similarly, Smart Economy (SE) Jobs (J) indicator number 1 (IND1) is represented as SE1. Also, Smart People (SP) Education (E) indicator number 1 (IND1) is signified as SP1 and so on.

Table 4.3: The Measurable Indicators Used to Assess the Smartness of Each Domain

Domain	Sub-domain	Indicator codes	Indicators	ISOs 37122 and 37120
Smart Governance	Finance	SG1	The extent to which the Sector Education and Training Authorities (SETAs) budget enhances municipalities' ability to support basic job skills development	13.4 - Percentage of municipal budget allocated for the provision of programmes designated for bridging the digital divide
		SG2	Utilisation level of ICT infrastructure for remote management and promotion of service payments by municipal residents	9.2 - Percentage of payments to the city that are paid electronically based on electronic invoices
	Governance	SG3	Satisfaction with regular training provided to staff to keep up with technological advancements	10.2 - Percentage of city services accessible and that can be requested online
		SG4	Percentage of modernised operations through improved data management	None
	Telecommunicatio n	SG5	Proportion of computers in municipal households	6.2 - Number of computers, laptops, tablets, or digital learning devices per 1,000 students
		SG6	Broadband internet access percentage in households	8.3 - Percentage of the city area covered by municipally provided internet connectivity
	Urban Planning	SG7	Implementation rate of planning documents like the IDP	21.1 - Annual number of citizens engaged in the planning process per 100,000 population
		SG8	The extent to which the regulatory framework is aligned with government laws	21.1 - Annual number of citizens engaged in the planning process per 100,000 population
	Community Participation	SG9	Percentage of roadshows organised to share and distribute information	10.4 - Voter participation in the last municipal election
	Public-Private-Partnership	SG10	Satisfaction with collaboration with the municipality on repurposing initiatives	5.5 - Number of businesses per 100,000 population
Smart Economy	Jobs	SE1	Share of promotion for alternative career paths for youth	5.4 - Youth unemployment rate
		SE2	Proportion of opportunities based on collaboration with the Tumbaga Foundation and CUT to enhance employees' technical skills	None
		SE3	Number of platforms for presenting fundable ideas	None
		SE4	Percentage of investment centres dedicated to supporting research and development efforts	5.4 - Percentage of employees employed in education, research, and development sectors
	Innovation	SE5	Number of individuals connected to apprenticeships and learnerships through municipal interventions	5.4 - Youth unemployment rate
		SE6	Transformation percentage of abandoned mine shafts into new employment opportunities	5.1 - Survival rate of new businesses per 100,000 population
	SMEs	SE7	Percentage of partnership with local businesses to promote employment opportunities	5.5 - Number of businesses per 100,000 population
Smart People	Education	SP1	Percentage of population with secondary-level education	6.3 - Percentage of students completing education

Domain	Sub-domain	Indicator codes	Indicators	ISOs 37122 and 37120
		SP2	Share of population with tertiary-level education	6.6 - Number of higher education degrees per 100,000 population
		SP3	Proportion of citizens benefited through collaboration with SETAs to enhance skills development	13.4 - Percentage of municipal budget allocated for the provision of programmes designated for bridging the digital divide
		SP4	Satisfaction with the Skills Levy Act to ensure annual staff training	None
Smart Living	Housing	SL1	The percentage of formal houses to total houses in the municipality	12.5 - Housing profile indicators
	Population Conditions	SL2	Widespread access to mobile devices and internet connectivity	18.1 - Population percentage with access to sufficient fast broadband
	Safety and Security	SL3	The proportion of violent crime within the community	15.5, 15.8, and 15.10 - Number of homicides, property, and crimes against women, respectively
		SL4	Satisfaction with visible policing and enforcing local by-laws effectively	14.1 - Percentage of city area covered by digital surveillance cameras
Smart Environment	Energy	SEn1	Satisfaction level of citizens with the provision and installation of street lighting	7.7 - Percentage of street lighting refurbished and newly installed
		SEn2	Level of investment in sustainable energy solutions, including solar and wind power	7.2 - Percentage of energy derived from renewable sources
	Waste	SEn3	The percentage of identified potential solutions to minimise waste	16.1 to 16.6 - Waste solutions
		SEn4	Level of investment to support plans to explore the use of waste-to-energy as a viable solution	16.5 and 16.6 - Percentage of city waste treated from waste to energy plants and biologically treated for use as gas
		SEn5	The proportion of negative impact caused by illegal dumping within the municipality	16.7 and 16.8 - Percentage disposed of in open dump and by other means
		SEn6	Satisfaction level of citizens with municipal waste management and collection scheduling	16.1 - Percentage of population with regular solid waste collection
	Sanitation	SEn7	The percentage of sewer networks and wastewater treatment works	22.1 - Percentage of treated wastewater being reused
	Water	SEn8	The share of people in the municipality who have access to piped water	23.1 - Percentage of population with potable water supply service
		SEn9	The municipality's coverage of smart water meters	23.3 and 23.4 - Percentage of city buildings and water distribution monitored by smart meters
		SEn10	Level of functional water distribution networks	23.3 - Percentage of city water distribution monitored by smart meters
Smart Mobility	Transport	SM1	Satisfaction with the integrated transport plan to enhance transport efficiency	19.8 - Transportation profile indicators
		SM2	Satisfaction rate with regulatory compliance for public transport systems	19.8 - Transportation profile indicators

From a total of 74 raw indicators presented in Table 4.1, Table 4.3 above provides a comprehensive summary of the framework's key sub-domains and 37 critical indicators that contributed to the framework's justification, organized by the six domains. These indicators are outlined as follows: smart governance and environment each consisted of 10, 4 for smart people and living, 7 for smart economy, and 2 for smart mobility, respectively. The domains serve as a framework for interpreting the *municipality's smart city ideal* and are discussed accordingly in this section.

4.4.2.3.1 Domain 1: Smart Governance

Evidence from earlier studies reveals several factors responsible for the successful implementation and performance of smart cities worldwide. The researcher is interested in using this criterion of the framework to evaluate the municipality's smartness across its sub-domains. Insights from some studies suggest that there must be ample time for effective governance, allowing residents to learn from the past, present, and future. On the contrary, the Matjhabeng IDP document was formulated and implemented within what can be argued to be one year. On this note, the researcher develops a term for execution timeliness.

Additionally, one of the study's fundamental objectives is to develop a framework for measuring the municipality's smartness. However, framework implementation cannot be achieved without systems in place for measurement. Hence, there was a need to empirically investigate the significant contribution of framework implementation to municipal smartness.

A cluster of six sub-domain areas of interest related to smart governance was identified, which can measure critical areas that could potentially guide governing bodies towards a more sustainable and innovative municipal governance environment. The first one is dedicated to the financial resources provided by the municipal authorities, the second facilitates the municipal governance operations, the third is related to municipal telecommunication, the fourth is the municipal authorities responsible for the overall planning of the institution, the fifth is critical since it involves community participation, and lastly, the public-private partnership stakeholders are considered necessary for the viability of public initiatives and measures. This domain splits into sub-domains and 10 must-have critical indicators, namely (*SG1, SG2, SG3, SG4, SG5, SG6, SG7, SG8, SG9, and SG10*) as follows:

4.4.2.3.1.1 Sub-domain 1: Finance

This criterion assesses the effectiveness of the government's financial resources in the governance sector. The assessment of the municipality's financial statements is critical, as they are the most comprehensive sources of information on the municipality's financial position and performance.

4.4.2.3.1.1.1 SG1: The extent to which the Sector Education and Training Authorities (SETAs) budget enhances municipalities' ability to support basic job skills development

This indicator measures the vital role of higher education training, as well as the corresponding clear municipal financial budget plan. Stimulating the local economy requires skilled employees prepared to enter the labour market; the national government directed SETAs to provide these skills, as well as the necessary funding to carry out this national request. This criterion evaluates the extent to which the SETA budget improves the municipality's ability to support basic employment skills development by collecting data on the budgetary resources allocated to the SETA for implementing training programs that equip citizens with these skills. The study's findings revealed that financial support for higher education, such as master's degrees and PhDs, is limited, hindering the growth of smartness and smart outcomes.

> *Even though they have been very strict, they would not give you money for you to teach people or to provide people to go and study for a master's degree or a PhD. They will only provide you with cash to give skills, short skills, skills that are necessary to do the job* (Participant 1).

As a result, the municipality should refocus its resources towards essential skills development that directly enhances employment performance and workforce preparation, rather than neglecting higher educational programs. Given these limits, the municipality should guarantee that skills development efforts directly address employability concerns, as measured by smartness. In addition, the impact of skills development enhancement cannot be realised until SEDA-funded training programs are thoroughly evaluated. Such measurement is achieved by gathering evidence from scores of competent individuals engaged in the labour market, along with information on SETA-backed training graduates. Employer feedback on trainees' preparedness and competency can provide further insight into the relevance and quality of training programs.

Furthermore, assessing the extent to which these programs align with current industry and business demands would help determine the municipality's efforts to alleviate skills shortages and increase employability. The purpose of these criteria should be to ensure that the skills learned are relevant to both municipal needs and broader job prospects. On that topic, the study's findings indicated that continuously measuring this indicator will yield results that may help prevent graduates from becoming unemployed by equipping them with practical, in-demand skills such as science, engineering, information technology, and mathematics, among others. In addition, it may be claimed that these criterion outcomes may assist individuals receiving training through municipal funding in being better positioned for work, leading them to contribute more effectively to smartness.

4.4.2.3.1.1.2 SG2: Utilisation level of ICT infrastructure for remote management and promotion of service payments by municipal residents

The municipality must develop and implement an ICT infrastructure to improve efficiency, service delivery, and economic growth. This indicator demonstrates how smartness evaluation can help ICT simplify processes, enhance communication with people, enable data-driven decision-making, increase transparency, and attract investment. For example, basic access to information and cashless payments via smartphones or other mobile technologies increase user productivity and convenience across all activities, demonstrating that IT adoption contributes to the municipality's smartness performance. Furthermore, simplified procedures include automating routine administrative tasks to reduce the time and effort required to deliver services. It incorporates everything from online permit applications to automated payment systems. Similarly, it modernises business practices, increasing efficiency and competitiveness whilst facilitating better policymaking. Although questionable, the study's findings show that Matjhabeng Municipality's policies have improved with its ICT advances, resulting in more efficient commercial operations that benefit citizens. Similarly, the development of digital payments has sparked the government's and other policymakers' interest, prompting them to review and develop a digital financial system that is safe, practical, efficient, and contactless for the community, thereby reinforcing the narrative that smartness equals technology. For example, Participant 3 shared the following relation below:

> *Payments for services can be made electronically, saving residents and businesses time.*

Within a municipality, implementing ICT infrastructure is crucial to improving citizens' quality of life, optimising government processes, and increasing business efficiency. It is critical to examine improvements in access to communication channel services and whether ICT enhances residents' convenience and satisfaction. Another important consideration in evaluating this indication is the municipality's recent use of technologically sophisticated processes, such as digital payments and data security applications, for data management. The appropriate level of smartness, in which a municipality employs digital technologies to improve municipal performance and well-being, reduce costs, and effectively and actively engage with residents' needs, should be assessed as well.

4.4.2.3.1.2 Sub-domain 2: Governance

This criterion assesses the smartness of the municipality's governance related to municipal administration. This governance refers to the actions and tools provided by authorities for:

4.4.2.3.1.2.1 SG3: Satisfaction with regular training provided to staff to sustain technological advancements

There is a strong relationship between this indicator and “ISO 10.2 - Percentage of city services that can be requested online.” Showing the 4IR in action, technological growth is impacting every aspect of life, enabling new and better ways to execute tasks inexpensively and save time. This endeavour requires technology infrastructure and a significant focus on training and developing individuals' skills within public administration. This framework requirement ensures that municipalities do not risk becoming obsolete due to their inability to adapt to more advanced technologies. As a result, to support IoT, the indicator underscores the importance of continuous assessment of upskilling and retraining in new technologies, which may provide a clear picture of training effectiveness, according to the findings. Participant 4 cites training opportunities available for municipal staff, specifically for technical skills:

> *Yes, short courses, yeah, lumbars. They have different training. Those working the roads have different training and so forth.*

The overall conclusions of this study encourage evaluating the training options available to municipal personnel, particularly for technical skills. As a result, key considerations include the cooperative benefits of combining human capital training with smart technology governance when designing and implementing innovative technology training programs, as well as ensuring that these programs are aligned with broader municipal objectives, as supported by Al-Mekhlafi, Al-Mekhlafi, Al-Kahtani, and Abdelmahmod (2024). Thus, by continuously monitoring this indicator, municipalities can assess overall performance in upskilling municipal personnel on the latest technical advancements and collaborative training interventions to alleviate the skills gap and increase promotion opportunities. As a result, it is expected that the current indicator will provide information that may assist in establishing objectives, assessing, monitoring, and managing smartness and performance, and in making decisions based on the preceding discussion.

4.4.2.3.1.2.2 SG4: Percentage of modernised operations through improved data management

This indicator assesses the effectiveness of adding a human element alongside technological advances in modernising data management systems. According to the literature, human-centred definitions of 'smart' all emphasise that technology is an enabler, not the source of smartness. This indicator examines municipal data owners, data managers, IT system administrators, data policy coordinators, data policy officers, and data governance to determine the smart state of the municipal ICT infrastructure environments under administration. It might include auditing existing processes to identify essential components of the municipality that require investment in sophisticated data management, data capture, and Big Data applications. However, key factors to consider include the extent to which technology adoption embraces emerging technologies, such as transparent transactions, and how the IoT can be leveraged to optimise supply chain management and serve the community's smartness interests. For example, Participant 3 shares their development below:

> *Furthermore, the Municipality has embarked on Smart Meters (both Electricity and water) using ICT infrastructure to control and promote user payment for services remotely.*

Additionally, measuring the tangible effects of human characteristics such as empathy and compassion on updated data management is critical to improving ICT skills, as a more appealing and adaptive system is developed and provides vital insights into the influence of such technologies. Arguably, smartness does not necessarily stem from technology but rather from the quality of life achieved through effective modernization; hence, frequent tracking of this indicator helps communities identify areas for future improvement.

4.4.2.3.1.3 Sub-domain 3: Telecommunication

According to this criterion, telecommunications within smart cities should be seen as another platform to expedite the diffusion of technologies at the municipal level by applying 4IR principles, thereby enabling cities to make more efficient use of resources in their operations. The framework enables the assessment of 4IR technologies as tools to assist municipalities with issues such as housing shortages, waste management, and Big Data analytics, thereby enabling greater smartness in traffic management, scheduling transportation services, and responding to emergencies more efficiently.

4.4.2.3.1.3.1 SG5: Proportion of computers in municipal households

This indicator assesses the extent to which municipal households have access to computers. It includes the following smartness assessment: essential instruments used for participation in the modern digital economy, education, and civic involvement. There is a match between this indicator and the "ISO 6.2 - Number of computers, laptops, tablets, or digital learning devices per 1,000 students." It underscores that access to technology and digital literacy are critical in every community; therefore, the proportion of computers in municipal residences is a significant indicator. As a result, the evaluation of this criterion should collect detailed data on households that possess affordable technological devices, such as at least one laptop, tablet, or desktop computer; these households should be compared to households in the municipality that lack these devices. Device ownership amongst residents can be measured through surveys, census data, interviews, or questionnaires, yielding these insights. In addition to this statistical data, computers are a major driver of socioeconomic progress; therefore, understanding the overall number of households owning computers is critical. Hence, it becomes essential to evaluate how people use these computers, specifically if they provide uniform access to education, work, and information via the devices, which allows for a more in-depth assessment of their value. Aiming to comply with 4IR criteria by investigating issues such as participation in governance necessitates considering citizens' digital literacy, which might help residents make better-informed decisions, whereas computer availability alone is meaningless. Consistent monitoring of this evaluation framework indicator may help determine whether such activities occur in a municipal setting and analyse the community's overall behaviour and attitudes toward computer acquisition initiatives.

4.4.2.3.1.3.2 SG6: Broadband internet access percentage in households

To enable trendy economic sharing, communication, and education, the proportion of households with broadband internet access is also vital; hence, this indicator critically examines the extent to which municipal households have access to high-speed internet. This criterion shows the extent to which broadband infrastructure is widely available and inexpensive, enabling citizens to actively engage in the municipal digital economy. As a result, agreements with commercial partners specialising in ICT infrastructure might lead to the creation of a reliable fibre network, which has sparked substantial interest among many government departments. The findings underscore that accelerating the deployment and maintenance of fibre infrastructure in public areas, such as parks, libraries, and community centres, benefits all residents through public-private partnerships. Similarly, the municipality's growth and development plan emphasises collaboration with other municipal agencies to establish a broadband infrastructure that supports the brilliant state notion and market. To assess this criterion, a collection of inclusive data on household proportions with broadband internet connections should be conducted across various internet service types, such as satellite, mobile broadband, and fibre-optic networks. ICT infrastructure enables the provision of a variety of ICT-enabled services. Participant 4 added that they want to facilitate this by conducting feasibility studies to explore the evidence of usage of cell phones, internet access, and dependability within the organisation:

> *So, what I am saying is that we need a plan. The plan might need to be supported by specific studies, including a quick feasibility study to assess the evidence for cell phone use, Internet access, and reliability.*

It remains critical to assess broadband accessibility and affordability; there is an enormous stake in supporting the development of locally owned and operated Wi-Fi networks in underserved communities, which has a significant impact on empowering residents to address their connectivity needs while ensuring affordability and accessibility, as high prices can be a barrier even in areas where infrastructure is available. Moreover, evaluating the quality of broadband service is critical to implementing regulatory guidelines that encourage healthy competition among internet service providers within the municipality, thereby reducing barriers to small firms seeking to enter the market. This involves evaluating investments in broadband literacy initiatives, fibre-optic broadband networks, higher internet speeds, greater reliability, and improved customer support. User feedback gathered through community interaction can provide insights into residents' real-world experiences, exposing concerns such as service disruptions, sluggish speeds, or insufficient coverage. Special emphasis should be placed on the rising pursuit of digital inclusion within communities. Furthermore, initiatives that educate citizens about the benefits of internet connectivity and provide training in critical digital skills to help people make the most of online resources and services should be evaluated.

Fiber-optic communication is ideal for control, observation, and spine communication in wide-area networks that require continuous tracing and monitoring. In that regard, this criterion evaluates the degree of investment by municipal authorities in ICT infrastructure operations in general, and the rollout of municipal internet broadband in particular.

4.4.2.3.1.4 Sub-domain 4: Urban Planning

The assessment framework for urban planning towards more innovative governance comprises two main areas of interest. The first area considers the identification of the current structure of the municipality in terms of planning documents like the IDP as a master plan, which gives directions to municipal operations, and the second area concerns the regulatory framework that must be aligned with the governmental laws to facilitate and motivate officials to achieve a more friendly workplace environment.

4.4.2.3.1.4.1 SG7: Implementation rate of planning documents like IDP

This indicator has a strong correlation with "ISO 21.1 - Annual number of citizens engaged in planning process per 100,000 population." As indicated in key planning documents, IDP is assessed based on the municipality's ability to implement its long-term strategies effectively. Municipal growth is heavily reliant on this strategy to address key areas, such as digital technology, smart governance, and community-wide decision-making, to improve service delivery and ensure effective municipal administration. To evaluate this indicator, one should collect the following critical data: IDP should present an extensive status report on the actions launched by the municipality, as indicated, including dates, revenue allocations, and completion rates.

This indicator entailed not only setting criteria and quantifying a municipality's smartness relative to other master plans that align with the IDP, but also evaluating the IDP as the principal legally mandated tool for governance. Participant 1, having a background in local administration, outlines how the IDP ought to be used as a reference point for planning and executing initiatives:

> *In your IDP, you must outline your master plan for infrastructure. Your master plan in terms of electricity, as well as your master plan in terms of skills development.*

Data gathering might include tracking the proportion of projects that are on track, either incomplete or entirely completed, and determining whether these projects achieve the municipality's intended objectives. By examining this indicator, the municipality can identify areas where the legislation mandates auditing of finished projects, as well as the review, updating, adoption, and implementation of the IDP to enable carrying out the document's increased constitutional task. The existence of this agreement goes a great way toward resolving the apartheid-cracked legacy by integrating multiple levels of government.

4.4.2.3.1.4.2 SG8: The extent to which the regulatory framework is aligned with government laws

The integrity of this indicator is assured since it is linked to “ISO 21.1 - Annual number of citizens engaged in planning process per 100,000 population.” The regulatory framework aligns with government legislation by comparing local rules to the regulatory requirements needed to ensure compliance with national laws. Thus, this indicator reflects the municipality’s commitment to enabling senior authorities, through legal governance, to ensure the consistent creation, utilisation, exchange, and preservation of information resources to measure smartness. To provide an accurate evaluation of this indicator, a detailed assessment of the underlying principles, planning methodology, coordination, and consistency of the legal system in smart cities is required. It is also crucial to establish whether there is a strategically designed regulatory structure that adheres to government regulations and ensures compliance. There is a need to assess the regulatory framework's efficacy and efficiency in enforcing rules. It includes tracing instances where application regulations proved inconsistent, resulting in court disputes, projects taking an extended period to complete, and compliance issues encountered with socioeconomic, human, legal, and regulatory reforms, which may necessitate retraining officials in legal matters. As such, corporations proactively build frameworks aligned with government rules to ensure compliance. Participant 4 elaborated on that as follows:

> *The other component is the regulatory framework we need to support, which outlines how the system will operate in accordance with this country's laws. To begin investigating those regulatory frameworks and separating the roles of the private sector and government, you need to define the boundaries.*

Frequent stakeholder input from businesses on the perceived performance of rules, as well as comments from individuals, can provide valuable data for legal practitioners. Frequent internal or external audits, reviews, public consultations, and engagement with higher government agencies are additional approaches to verifying that this municipal regulatory system is up to date and compliant with national legislation. Municipal initiatives to improve legal operational clarity and efficiency, for example, might improve citizen trust and confidence in the regulatory system.

4.4.2.3.1.5 Sub-domain 5: Community Participation

According to smart governance, the sustainable use of ICT enables improved information and service delivery and encourages citizen participation in decision-making. The purpose of this criterion is to assess the smartness of roadshows organised to share and distribute information to the community, and the involvement of citizens in municipal decision-making processes.

4.4.2.3.1.5.1 SG9: Percentage of roadshows organised to share and distribute information

Its focus on citizen participation makes it closely related to "ISO 0.4 - Voter participation in the last municipal election." As such, this indicator evaluates a key aspect of smart cities: public participation, specifically citizen engagement in urban planning processes. This indicator assesses how effectively the municipality reaches the rest of the community by actively developing initiatives to engage youth in economic development and decision-making through community roadshows that inform residents about new policies, services, and/or opportunities offered by the municipality. It recognizes the critical role of local knowledge and experience in each community, enabling respondents' remarks to be presented within the framework of community planning. Evaluating the efficacy of these roadshows entails traveling to various parts of the municipality to enlighten young people about municipal initiatives and to provide a forum for their perspectives, especially in remote areas. Further, this evaluation might be realised by building an open government process for making policy decisions and efficiently communicating information to citizens.

Additionally, this indicator measures citizen participation and engagement in the procedures that implement smart city principles within the municipality. This may be measured by undertaking subsequent visits to local businesses, encouraging children to participate in groups, and developing relationships that could lead to jobs. As such, the assessment results of this indicator on public participation may play a vital part in establishing the essential principles.

4.4.2.3.1.6 Sub-domain 6: Public-Private Partnerships

This criterion demonstrates partnerships with private-sector companies and start-ups, universities and research institutions, citizens, and civil society organisations, which are a critical part of building smart city infrastructure, mainly through ICTs to create data platforms and address privacy concerns, as well as through collaboration in municipal development. Through this indicator, the municipality has allocated a considerable amount of money to smart city concept projects over the years and has leveraged private sector investments in the process.

4.4.2.3.1.6.1 SG10: Satisfaction of collaboration with the municipality on repurposing initiatives

Assessing smartness for this indicator involves evaluating the satisfaction of various stakeholders, including but not limited to community members, public-private partnerships, and non-profit organisations, with the municipality's initiatives to repurpose obsolete infrastructure. This indicator reflects how effectively and inclusively the municipality considers stakeholders in its repurposing efforts. For example, in the transformation of old and dilapidated buildings, the revitalisation of industrial sites, and the restructuring of underutilised infrastructure to meet current needs for economic growth, such as incubation and innovation hubs, the green economy, community centres, and land spaces for affordable settlement to the benefit of community members. In assessing this criterion, specific details, such as surveys and stakeholder comments on their satisfaction with the performance of the municipal repurposing activities, as well as transparent involvement throughout the process, might provide insight and public confidence. Questions may arise about the effectiveness of municipal partnerships, repurposing projects, and the alignment of their impact with the community's needs. As Participant 2 stated, the municipality is required to develop methods to encourage mining tourism while simultaneously supporting local companies:

> *And then, as the municipality. We are going to. Take these small businesses or others* (Participant 2).

Additionally, repurposing projects yield observable benefits, such as job creation, a healthier, regenerated environment, and economic growth, which aid in the successful assessment of the municipality's public-private partnership effort. It is also critical to include residents' voices when planning repurposing initiatives and to incorporate them transparently into decision-making. Considering a broader picture of the advantages of repurposing activities, a healthy environment, and community consultation, among other endeavours, significantly adds to insight success. The lasting benefits of repurposing activities might be realised by instilling a positive attitude, as repurposing projects are frequently adjusted by municipal policies to continue serving residents' needs through periodic evaluation of this indicator. As a result, this component of the framework demonstrates that promoting public-private partnerships can be an effective way to examine economic repurposing. This indicator should be considered a motivating factor for collaboration with private enterprises to realise public-private partnership benefits.

4.4.2.3.2 Domain 2: Smart Economy

The economy is at the heart of people, policymakers, and all stakeholders. Meanwhile, the effectiveness of measuring smart city smartness using economic indicators varies across municipalities. The objective of measuring its smartness level addresses economic issues in the municipality. A smart economy aims to primarily measure the municipality's financial stability and productivity, as well as the level of introduction and implementation of new, innovative ideas. On this note, the framework must measure the economy's contribution to smartness. One of the contributions, as evidenced by the literature, is the cashless policy, which eventually reduces the amount of paper money in circulation, thereby improving citizens' quality of life.

This domain splits into three mentioned sub-domains and seven required critical indicators (namely *SE1, SE2, SE3, SE4, SE5, SE6, and SE7*) as follows:

4.4.2.3.2.1 Sub-domain 1: Jobs

4.4.2.3.2.1.1 SE1: Share of promotion for alternative career paths for youth

This indicator has a strong link to the "ISO 5.4 - Youth unemployment rate," which enables it to serve as a critical, seamless measurement. When measuring smartness for this criterion, the extent to which the municipality actively promotes and supports the youth with different skills and training as career prospects beyond traditional corporate and academic courses is considered. Unemployment poses a significant concern for South African youth, particularly graduates. Other alternative routes for young people considered for evaluation in this indicator include the effectiveness and criticality of technical-vocational training incorporating entrepreneurship training, university training for highly specialised skills, and arts and creative career paths. To address the overflowing employment market in this criterion, students should be encouraged to pursue other career pathways, such as plumbing, electrical professions, and information technology. Additionally, skilled artisans such as plumbers and electricians are crucial to addressing critical challenges in power and water delivery, as these skills are currently in limited supply in the municipality. A respondent stated the following:

> *Our emphasis is only on skills in plumbing, electricity, IT, and other areas that will enhance and embellish our efforts to ensure we provide excellent services to our communities*. (Participant 1).

As such, to evaluate this criterion, extensive data must be collected from various institutions on their programs, which include types of mentorships, workshops, and internships, as well as the degree of involvement of young people. Collecting such data entails tracking municipal outreach programs such as career fairs, organising local seminars for skills development, and private-public partnerships with higher education institutions promoting various qualification courses.

Furthermore, the overall number of young people participating in initiatives and activities aimed at developing their abilities, as well as the impact of these events, deserves examination. The collection of such feedback from employers of youth and young people themselves, as entrepreneurs, regarding the information they gained from municipal activities such as career fairs and skills development workshops, is vital. As mentioned earlier, it informs how these activities contributed to their success and highlights how these interventions improved the overall outcome. By regularly monitoring this indicator, the municipality can effectively plan and manage unemployment, which remains a serious challenge among South African youth.

4.4.2.3.2.1.2 SE2: Proportion of opportunities based on collaboration with the Tumbaga Foundation and the University of Technology to enhance employees' technical skills

Assessing the smartness of the proportion of opportunities based on collaboration with the Tumbaga Foundation and the University of Technology to improve employees' technical skills includes evaluating how the workforce benefits from technical skills development through this partnership's effective contribution. This indicator reflects the municipality's collaboration with these two stakeholders in developing employees' abilities, such as critical thinking, problem-solving, and effective communication, to prepare them to tackle workplace issues. This indicator is evaluated using data on the number of workers who obtained qualifications through institutions' development skills programmes. Therefore, this information is gathered by tracking the university courses offered, the types of qualifications provided by the institutions, and the number of stakeholders collaborating with these institutions to obtain such qualifications. Industry organisations such as Matjhabeng offer work-integrated learning to the institution. Likewise, university skills are an essential factor in reducing youth unemployment by improving students' employability (Paunović, Müller, & Deimel, 2022). Collaboration with the Tumbaga Foundation and the University of Technology was one example of such an approach taken. Regardless, this criterion should, among other things, quantify smartness in terms of a link between university skills, such as exceptional IT education, and the development of citizens who are highly employable, digitally literate, and capable of participating in city processes, a sequence of events that starts with fundamental IT skills instilled in citizens in their early years. Participant 1 describes the initiatives adopted by the municipality:

We have also developed an MoU with the Tumbaga Foundation, but it is not on the side. Again, that is why I want to emphasise that, because my understanding of your question is that there is nothing specifically in research. Our emphasis is on technical skills, employee empowerment, and, primarily, the skills I have mentioned: plumbing, electricity, and IT.

In this way, the university becomes a centre of smartness in the municipality. It accomplishes this through the deployment of modern technologies such as AI, IoT, and data analytics, as well as automation, to improve citizens' experiences and equip them with the necessary skills in a rapidly digitalising world, as organisations seek competent human resources with 21st-century capabilities.

Furthermore, to understand the influence of staff development on municipal partnership results, evaluation is critical. This includes continuous evaluation of development outcomes, such as employee performance on technical duties, advancement in critical thinking, improvement in problem-solving, advancement in service delivery, and overall improvements in their respective accountability to the municipality. The success of the provided training and the earned qualification might be further assessed by gathering information from both participants and employers on how municipal requirements and skills demands align with these opportunities. Likewise, this indicator should be used to track the long-term benefits of such collaborations, including, but not limited to, increased work morale, increased productivity, appreciation for the working environment, higher job satisfaction, and enhanced skill set within the municipality. This municipality may identify areas for improvement in these collaborations using the findings of the evaluation of this indicator, optimise skills development initiatives, and ensure they contribute to a highly trained, competitive workforce.

4.4.2.3.2.1.3 SE3: Number of platforms for presenting fundable ideas

This indicator comprises assessing young innovators' access to economic development financing opportunities and the availability of assistance in presenting their ideas to a broader audience, thereby making their abilities visible to commercial groups. This statistic indicates a significant proportion of unemployed educated young people and assesses citizens' contributions to society, including their ideas, insights, tensions, and political instability. This criterion is evaluated by collecting the total number of venues for presenting ideas, such as roadshows, startup contests, corporate boards, community centre creative events, and youth ideas exhibitions, that are made available by the municipality. Participant 2 underlines the need to invest in youth ideas and offer forums for youth growth, such as roadshows, to align with the municipality's aims:

> *This is how FDC can help them. We tell them to give us their ideas; if they come up with one, you have a way to execute it, and these are the people you can contact. If you need funding, we are even in the process of refurbishing.*

As such, these platforms should be sufficiently diverse to address, among other things, technology, technical skills, and various SMEs, each of which must be identified and recorded. Furthermore, the number of roadshows, startup competitions, youth idea exhibitions, and overall local activities with an economic impact must be evaluated to determine the overall success rate of these platforms in connecting innovative ideas to relevant funding sources. Participants' responses can provide insights into how effective these platforms are at turning these ideas into action. This indicator enables a municipality to assess the capability of its innovation environment, identify gaps in roadshows and other platforms, and ensure that these platforms are adequately developed, easily accessible, marketed, inclusive, and improved in the future to support a set of innovative ideas, particularly from young people. Participant 2 also emphasises how these platforms enable conversation between young people and their needs, as well as stakeholders who impact decision-making:

> *That is why, when I was about to conclude, I said that after these people have presented, we would hear from them. Their ideas, then, we hear from them in order, as you say, to improve the economy. What must be done is to make them aware that they must create employment.*

4.4.2.3.2.1.4 SE4: Percentage in investment centres dedicated to supporting research and development efforts

This indicator assesses the number of funds a municipality has invested in improving technology infrastructure, research and development centres, and innovation incubation efforts to strengthen its economy. This indicator is closely aligned with "ISO 5.4 - Percentage of employees employed in education, research, and development sectors." This indicator reflects the research and development environment established by the public-private partnership effort, which is critical for improving the following sub-domains: healthcare, wastewater, education, and governance. This criterion is based on the overall financial investment and funding for research and development projects available at municipal research centres. Moreover, municipal partners in research initiatives, such as Technical and Vocational Education and

Training (TVET) colleges, universities, SETAs, private businesses, innovation and research institutions, and institutions of higher learning that support emerging young and experienced researchers with advanced, substantial, and innovative projects, should be identified. Similarly, these partnerships not only strengthen the municipality's capacity for innovation but also provide opportunities for local talent development and the recruitment of technologically advanced firms, thereby fostering a more dynamic and competitive economic climate, underscoring the importance of their appraisal. Participant 1 advises that the municipality partner with educational institutions not only for effect, but also to improve the skills and employability of its employees and participants:

> *To the municipality's benefit, while at the same time ensuring that those who have acquired those skills become employable, even if they do not work here, they will still get employed, whether in Cape Town or Johannesburg.*

Thriving local economies, improved healthcare facilities, and better service to residents are just a few examples of success that can be used to assess the efficiency of research and development centre investments. This criterion also implies that increased research employment, improved research publication output, and the creation of novel products and services through research projects can serve as confirmation that investment in research and development centres is profitable. By regularly reviewing this indicator, the municipality can help determine the total investment required to improve the research centre's effectiveness and support a better, more informed economy grounded in knowledge.

4.4.2.3.2.2 Sub-domain 2: Innovations

The smart economy dimension encompasses economic development, industrial plans, innovation generation, and entrepreneurial clusters. The ease of starting a business measures this criterion's smartness, the creation of job opportunities, and the motivation for entrepreneurship, particularly amongst young people. Understanding the rationale for evaluating smartness and the perceived benefits to society at large of this move is critical because seeking innovation in technological and political fields, such as the municipality, is an instrument of an innovative economy. Furthermore, as the innovation component makes a municipality more competitive and better able to attract further investment and skilled labour into the region, the economic growth prospects it enhances make its smartness evaluation even more critical.

4.4.2.3.2.2.1 SE5: Number of individuals connected to apprenticeships and learnerships through municipal interventions

The rate at which citizens have access to labour opportunities, experience, and benefits that align with their needs is determined by the efficacy of municipal initiatives. The labour market and businesses demand that individuals possess highly skilled and practical experience and knowledge before joining the workforce; hence, this indicator measures the municipality's obligation to provide opportunities and bridge the visible gap between employment and education. Hence, it is critical to collect information on the number of individuals involved in workplace-based learning (WPBL) programs, such as learnerships and apprenticeships, within the municipality before assessments based on this information can be conducted. It can include both the private and public sectors, except for the municipality. The collection of this data can be traced back to the number of organisations that provide such programs to members of the community, including, but not limited to, police departments, government departments such as home affairs, SETAs, social development, educational institutions, and, particularly, local businesses.

This study revealed that the municipality held a highly critical perspective on WPBL programs, recognising their significance to the community and students. Participant 1 contributed to the method by which the municipality executes these experiential learning courses to develop skills and strengthen IoT systems. Participant 1 emphasises the value of such programmes:

> *The students who are graduating here or are still studying with you. They are absorbed by us as an entity, as a municipality, to gain experiential learning in our entity. I know we have students who are.*

In addition, it is critical to assess the following success factors regarding the number of WPBL programs offered: individual completion rate, number of employed individuals, and the track record of individuals employed following participation in the programme. Furthermore, remarks from prior participants and employers on the program's efficacy, quality, and overall impact on their quality of life from participation in the training can shed light on the WPBL's contribution to the local community. Data on individual workforce retention, whether through permanent employment or ongoing skills development, therefore, needs to be included.

4.4.2.3.2.2.2 SE6: Transformation percentage on abandoned mine shafts into new employment opportunities

The fact that this indicator matches "ISO 5.1 - Survival rate of new businesses per 100,000 population" signals its reliability and its ability to measure smartness. This indicator assesses the extent to which municipalities investigate ways to transfer these lands for redevelopment, with an emphasis on diversifying their economies by pursuing alternative businesses and providing new job opportunities. This indicator illustrates how activities such as generating new industrial possibilities, diversifying employment, and collaborative efforts may effectively develop and revitalise local areas that were formerly economically dependent on mining. To correctly evaluate this indication, data must be gathered from shafts that were recently reused and reconfigured for new industrial use, as well as from the various enterprises that have emerged from abandoned shafts. Furthermore, vital information, such as the number of jobs created by the changed shafts and the number of community members who benefited from the transformation, is critical for evaluating this indicator. As such, this knowledge requires an examination of strategies to ensure economic sustainability, particularly for modified mineshafts. By continuously monitoring and assessing the fraction of abandoned mine shafts, a municipality might employ collected data to analyse and gain insights into how to restore local economies and create community resilience. Participant 2 expresses interest in clarification on how to treat abandoned mining shafts, with particular emphasis on the potential transfer to municipal authorities for future action. In their words:

> *Is the. What do we do? Just like that one I talked about, we contacted the tea company. Alternatively, you are planning to. Close this shaft. What are you going to do with this thing? Can you? Maybe. Ah. Transfer this property. Please give it to the municipality* (Participant 2).

In addition, this study found that supporting small businesses may be a perfect approach to exploring the repurposing of old mines. As mentioned by Participant 2, the municipality must continue to find ways to promote mining tourism while also supporting local businesses:

> *And then, as the municipality. We are going to. Take these small businesses or others* (Participant 2).

4.4.2.3.2.3 Sub-domain 3: SMMEs

4.4.2.3.2.3.1 SE7: Percentage of partnership with local businesses to promote employment opportunities

This indicator assesses the extent to which the municipality collaborates with local enterprises to create job opportunities and economic growth. This indicator is deemed a strong link between the "ISO 5.5 - Number of businesses per 100,000 population." This criterion demonstrates how a strong public-private partnership can create employment, support SMEs, and foster a thriving job market. Initiatives such as WPBL programs, practical skills development training, and workshop organisations can provide data for measuring this criterion. Analysing the companies that form part of the partnership and offer job opportunities to the municipal community, across sectors such as industrial, retail, construction, and technology, may help determine whether the municipality is succeeding in establishing employment opportunities across multiple sectors. The effectiveness of these collaborations is evaluated based on the following outcomes: the quantity and quality of job opportunities created, and the groups of people who benefit from these opportunities, including people living with disabilities, young people, women, and/or previously disadvantaged communities. The collection of data, such as the number of job placements, successful training workshops, and economic development, through regular monitoring of public-private partnerships, helps assess the impact of these collaborations on the municipal economy. By examining the percentage of partnerships with local firms and efficiently leveraging data, the municipality may position itself to provide the finest and highest quality of service to its communities:

> *Partnerships with the private sector so that it could be your triple arrangement, or it could be direct partnerships, for example, to roll out, let us say, we are looking at your high fibre networks, we are going to create those opportunities and partner with investors for us to roll out all those types* (Participant 2).

4.4.2.3.3 Domain 3: Smart People

As the research community strongly emphasizes, the municipality's complexity lies primarily in the involvement and coordination of numerous actors with diverse interests and needs, and in some cases, conflicting interests. Therefore, this criterion should assess the smartness of the people involved in the municipality, and their ability and willingness to use tools and techniques in the framework of their occupation is crucial.

Interestingly, the smart people domain refers to a smart municipality at the citizens' level of education and societal interaction. Hence, human and social capital are crucial for improving productivity and promoting smart living in a municipality. Subsequently, higher education institutions, such as universities, are essential for developing human capital because they act as knowledge mediators, custodians, and providers of activities to support people in becoming smarter. For this reason, this criterion should reinforce section 4.4.2.3.2 of this Chapter by measuring citizens' creativity and innovation, as well as their learning skills that guarantee employability and competitiveness. This domain has one sub-domain and four required critical indicators (*SP-E-IND1, SP-E-IND2, SP-E-IND3, and SP-E-IND4*), which are discussed as follows.

4.4.2.3.3.1 Sub-domain 1: Education

4.4.2.3.3.1.1 SP1: Percentage of population with secondary-level education

The development of national education is a crucial benchmark for everyone, and secondary schooling for those who have completed this level is critical; thus, its assessment is essential. This is a vital indicator that is closely linked to "ISO 6.3 - Percentage of students completing education." Individuals' higher education qualifications and involvement in the professional world are entirely dependent on secondary school, which provides essential abilities such as reading and writing, counting, and critical thinking. A municipality with a higher percentage of people in secondary school has a higher level of intelligence in decision-making, which leads to better employment opportunities. It is also associated with higher employment rates, greater access to university education, and a greater sense of duty to society. On the contrary, difficulties such as insufficient postsecondary education, limited economic growth, high illiteracy rates, and a lack of entrepreneurs may be associated with a lower percentage of secondary education.

Tracking this statistic can help local high-ranking officials make educated decisions about the efficiency and improvement of their education systems. The examination of school performance enables a municipality to make the best decisions concerning where to intervene in schools that require it, such as recruiting educators, upgrading teaching and learning facilities, and enhancing equality within the education system. Finally, examining this indicator can provide insights into the proportion of the population that completes secondary school, as well as the proportion that is capable, knowledgeable, and competitive in society, among other abilities.

4.4.2.3.3.1.2 SP2: Share of population with tertiary-level education

The indicator measures the proportion of persons in a population who have completed higher education qualifications, such as university degrees, certificates, or comparable certifications. This indicator matches with "ISO 6.6 - Number of higher education degrees per 100,000 population." This criterion measures the workforce's skill set and knowledge through the municipality's human skills development initiatives. This municipality requires a self-driven innovation effort, economic growth promotion, and opportunities for citizens' personal development, all of which are associated with higher employment rates, greater income prospects, and a higher quality of life. Similarly, obstacles that may arise due to a low percentage of qualified individuals include financial constraints, a low university M-score, insufficient desirable qualifications, or a poor secondary education pass mark. The study findings indicated that the number of people pursuing university education has not risen much over the last few decades. All these challenges make it more difficult to obtain a higher degree.

> *Not all of them could even be accepted by the university, as some do not have metric or beyond-metric qualifications. So, it is a problem for you, and it has brought us to this* (Participant 1).

The success of municipal higher education institutions' policies may be judged using this metric. It also grants insights into worker preparedness for knowledge-based businesses, which can influence economic diversification and technological growth. A municipality with a larger percentage of residents with good post-secondary education attracts more foreign investment. It promotes job growth, resulting in competent workers hired and retained by large firms. Furthermore, by examining this criterion, the insights it yields may help municipal officials engage citizens in an informed manner, making it a key standard for future growth.

4.4.2.3.3.1.3 SP3: Proportion of citizens benefited through collaboration with SETAs to enhance skills development

This indicator's relationship to "ISO 13.4 - Percentage of municipal budget allocated for provision of programmes designated for bridging the digital divide" makes it far more reliable in quantifying the municipality's digital readiness. SETAs were created by the Skills Development Act 1998 to address the weaknesses of the post-school education and training system and to lead the development of skills within economic sectors (Motala, Ngandu & Mncwango, 2021). This indicator measures the efficacy of collaboration among SETAs, stakeholders, and the municipality in determining the availability of workforce skills. This indicator illustrates SETA's success in playing a critical role in skills development, thereby enabling more effective service delivery to the local community. The findings revealed that 4IR has led to increased demand for technological advancement, necessitating the training of more skilled individuals in the municipality's areas of scarce skills. For this reason, this indicator seeks to accurately measure the proportion of citizens who benefited from this collaboration. As a result, the government has established SETAs, each focusing on a different economic aspect. To determine their statistical contribution to citizens, a consistent quantification of this criterion should be carried out to assist in developing sector skills plans, setting up learning programs, and monitoring employer skills training programmes.

Many partnerships between entities such as SETAs and municipalities suggest that assisting in the creation of smart cities by developing the requisite IoT infrastructure enhances workforce skills. A low level of collaboration might indicate a low rate of persons with labour market skills, as well as the ineffectiveness of the partnership in terms of the training provided. Participant 1 highlights the municipality's initiatives to engage with various SETAs, resulting in the successful securing of employment opportunities in financing-related skills. However, they point out that funding is restricted for more intellectual endeavours:

> *Tried numerous times to knock cells to the SETAs. The SETAs, as you know, have funding from the national fiscus to ensure that we, as government entities, can help our communities and residents develop the skills they need to achieve and retain them. Though they have been very strict, they would not give you money for you to teach people or to provide people to go and study for a master's degree or a PhD. They will only give you cash for skills, short skills, skills necessary to do the job* (Participant 1).

To put it simply, tracking this indicator to assess the impact of SETAs is critical for providing insights that might help solve the skills gap municipal workers need to serve their communities better. In summary, this criterion highlights how a lack of capacity and skills development opportunities, as well as the availability of training options to the Matjhabeng community, can be beneficial.

4.4.2.3.3.1.4 SP4: Satisfaction with the Skills Levy Act to ensure annual staff training

Building on previous education sub-domain indicators, this criterion assesses the efficacy and satisfaction with the Skills Development Levy Act (SDLA), another intervention aimed at addressing concerns about inadequate governance among top managers in local government. The municipality adopted various South African Government legislations and policies, including the 1997 White Paper on Local Government, the SDLA (No. 97 of 1998), the Local Government Municipal Structures Act (No. 117 of 1998), the Municipal Systems Act (No. 32 of 2000), and the Municipal Finance Management Act (No. 56 of 2003) (Davids, Houston, Steyn Kotze, Sausi, Sanchez Betancourt, Pienaar, Kanyane, Viljoen, Ngqwala, Mchunu & Fokou, 2022). Thus, the indicator caters to numerous aspects that require examination of this criterion, which include the following: (1) Taking a slight salary cut to fund training efforts for top municipal administrators. (2) In addition, the Skills Development Act requires municipalities to pay a skills tax of one percent of payroll to the South African Revenue Service to finance specified sector skills development efforts. This raises municipal revenue while upskilling municipal workers, ultimately improving municipal government. (3) This indicator measures how successfully this intervention promotes training activities for both junior and senior municipal workers, thereby improving municipal administration. High satisfaction ratings indicate that SDLA is effectively increasing municipal income while upskilling municipal workers, hence improving municipal governance. Participant 1 cites the role of the Skills Levy Act:

> *I think there is, remember, under the Skills Levy Act, money is deducted from their salaries, both for politicians and administrators.*

4.4.2.3.4 Domain 4: Smart Living

A smart city is said to be performing well if it can integrate social cohesion. As a result, this criterion of the framework should measure the municipality's smartness based on social integration through technological apparatus and assess its ability to accommodate the municipality's population growth. The smartness assessment in this domain underpins the belief that smart city technologies, beyond the internet and social media, have promoted social interactions beyond a reasonable doubt. For example, the availability and non-availability of technologies such as Wi-Fi and IoT, which enable people worldwide to access current events as they happen and interact with people in different parts of the world, require assessment.

This domain splits into three mentioned sub-domains and four essential indicators (*SL-H-IND1, SL-P-IND2, SL-S-IND3, and SL-S-IND4*) delineated as follows:

4.4.2.3.4.1 Sub-domain 1: Housing

4.4.2.3.4.1.1 SL1: The percentage of formal houses to total houses in the municipality

This indicator is equally essential to other indicators assessing formal housing, such as those of ISO, which include housing quality requirements and socioeconomic factor stability; a good example is “ISO 12.5 - Housing profile indicators.” Furthermore, this indicator shows the proportion of formal, well-constructed, liveable residences that meet legal standards, such as partitioning laws, durable materials, and sufficient infrastructure, to measure the quality of buildings intended for communal use. The existence and visibility of numerous illicit informal residences point to unexpected development and poor municipal governance. A high percentage of formal housing shows successful urban planning, availability of essential amenities such as clean water, sewage, and electricity, and, most importantly, an improvement in residents' quality of life. It shows that the municipality is effectively supporting long-term growth among its inhabitants, with a firm commitment to ensuring safe, secure housing that complies with property rules and regulations. This indicator examines and provides results that may be used to gain insight into the effectiveness of affordable housing initiatives and efforts to reduce informal settlements and housing inequality by increasing the percentage of formal housing.

4.4.2.3.4.2 Sub-domain 2: Population Conditions

4.4.2.3.4.2.1 SL2: Widespread access rate to mobile devices, internet connectivity

This indicator examines individuals' capacity to report municipal challenges experienced daily, utilising technical infrastructure and internet access, as well as their rate of resolution. This indicator measures the effectiveness of mobile network infrastructure and services, whether web- or app-based. This indicator equally matches the “ISO 18.1 - Population percentage with access to sufficient fast broadband.” A well-connected community is defined by a high rate of digital devices and internet connections, where technological advancements and the increasing prevalence of smartphone use, IoT, and digital apps and platforms serve as catalysts for developing smartness. Various platforms used by public and local institutions, such as social media, e-commerce, e-government, and cloud computing, are critical to achieving local smartness; therefore, the assessment framework should measure this indicator by assessing the technologies made available to citizens to improve their quality of life. Furthermore, assessing the impact of connection on the rate of access to digital devices such as smartphones, tablets, and laptops, as well as the speed at which they are accessed, can provide extensive insights into how digital device access influences daily life. This criterion focuses on the technology used and the speed of service, recognising features of smartness while reaching the required quality of life. When combined with appropriate software, a mobile device may promote human connection while also providing a few services. In contrast, a low access rate creates a municipal digital gap that might restrict citizen groups' access to and use of municipal services, thereby undermining smart city initiatives.

4.4.2.3.4.3 Sub-domain 3: Safety and security

Smart city indicators often refer to data, digital access to information, intelligent monitoring, and automated activities. This subdomain measures crime and death statistics, while a smart city focuses on the percentage of the city covered by surveillance cameras. Effective enforcement of the bylaws requires some work to transform them into a meaningful impact on citizen safety and security.

4.4.2.3.4.3.1 SL3: The proportion of the violent crime rate within the community

Critical community engagement is the first step in assessing this indicator, followed by law enforcement performance and thorough crime statistics, among other factors. House robberies, murders, hijackings, human trafficking, assaults, and gender-based violence are all evaluated using this indicator. Weaknesses in law enforcement, insufficient community participation, and high crime numbers indicate and/or contribute to a high degree of criminality among community members. Relevant organisational data, such as police reports, victim surveys, security camera footage, and emergency medical service records, may be accessed to obtain the data needed to accurately measure the criteria. For instance, this indicator can evaluate the proportion of violent crime rate by actively watching, recording, and responding to surveillance footage as one approach. To gain a deeper understanding of the effectiveness of crime-prevention and crime-combating measures, citizen viewpoints on safety and security issues can be evaluated through a qualitative survey. According to the study findings, while implementing operational strategies in the department, Participant 5 emphasises the importance of maintaining municipal safety and security, as well as the integration of intelligent monitoring systems, which might be enhanced in the future:

> *But our sole objective? It is on the security and public safety. That is what we wanted; we said the regulatory framework would be supported by both the plans and policies, if necessary, even by laws.*

Furthermore, this indicator evaluates the use of camera technology based on its ability to identify crime scenes in real time, assist in the capture of criminals, rescue victims, and, most importantly, collect criminal forensic evidence. Similarly, frequent monitoring and measurement of surveillance cameras may provide insights into their usefulness, which policymakers can then utilise to inform vital decision-making. The “ISO 15.5, 15.8, and 15.10

- Number of homicides, property, and crimes against women, respectively" is closely linked to this indicator.

4.4.2.3.4.3.2 SL4: Satisfaction in visible policing and enforcing local by-laws effectively

The assessment of satisfaction with visible policing and the enforcement of local bylaws effectively requires an interactive approach that involves gathering information from the community and crime statistics from safety and security authorities. This indicator measures citizens' well-being and their trust in authorities regarding safety, which is influenced by the high visibility of police enforcing the law and adhering to regulations. The police's ability to act quickly at crime scenes while balancing community needs results in high community satisfaction. In contrast, a low ability to enforce the law, police invisibility, unfairness, inefficiencies, and slow response to crime scenes equals a low level of trust and satisfaction from the community. To investigate the effectiveness of police officers' reactions, public opinion on police visibility, law enforcement, and general policing work, this indicator can be evaluated by collecting data such as police patrol visibility reports, conducting surveys on citizens, and public imbizos (a municipality road show initiative aimed at involving and gathering direct citizen perception and inputs) that can afford policing performance objective insights. Equally crucial is evaluating how effectively visible police are instilling a sense of security in communities and how well this correlates with crime reduction. Through habitually measuring policing practices, the municipality may use lessons learned to enhance public trust, reduce crime, improve safety and security, and encourage more communities to abide by the law. This indicator matches that of "ISO 14.1 - Percentage of city area covered by digital surveillance cameras."

4.4.2.3.5 Domain 5: Smart Environment

Like measuring smart cities based on technology, the economy, and other factors, technology in a smart city predicts natural events in our environment. To highlight a few points from previous chapters, municipal developers have recently installed technologies such as weather and earthquake sensors to predict, monitor, and inform municipal residents about weather conditions. By doing so, they can predict and avert any potential danger in the environment. Similarly, in this criterion, smartness is measured considering the following environmental aspects: energy, solid waste, sanitation, and water (*SEn1, SEn2, SEn3, SEn4, SEn5, SEn6, SEn7, SEn8, SEn9, and SEn10*). This is done as follows:

4.4.2.3.5.1 Sub-domain 1: Energy

4.4.2.3.5.1.1 SEn1: Satisfaction level of citizens with the provision and installation of street lighting

When evaluating residents' level of satisfaction with street lighting provision and installation, both the efficacy and technical features of the infrastructure are considered, as perceived by citizens. This indicator is strongly linked to the "ISO 7.7 - Percentage of street lighting refurbished and newly installed." This indicator quantifies the municipality's preparedness and determination to provide vital services, such as appropriate community illumination, regular maintenance, and overall protection upgrades, to realise community demands. Several satisfaction factors for street lighting are rated as low or high in this indicator: high satisfaction indicates that infrastructure is well-organized and functioning reliably and effectively, resulting in public safety and trust, whereas issues such as frequent outages, insufficient coverage, and poor maintenance, among others, lead to unreliability and inconsistency, potentially highlighting low community confidence and satisfaction. Critical information can be gathered by conducting surveys of individuals to assess this criterion: their satisfaction with the location, lighting, and trustworthiness of the municipal infrastructure. Furthermore, the influence of street lighting may be evaluated by analysing municipal maintenance department records of the total number of defective or non-functioning lights and by comparing crime rates in adequately lit areas with those in inadequately lit areas, thereby providing objective evidence. Equally significant is the gathering and analysis of municipal street lighting geographic data, which could be used to determine distribution and detect coverage gaps. Furthermore, the continued operational success of energy-saving technologies, such as LED, solar-powered, and intelligent lighting systems, needs to be considered. The municipality might enhance community safety, nighttime visibility, and overall public satisfaction with urban services by regularly monitoring, improving, and evaluating street lighting infrastructure.

4.4.2.3.5.1.2 SEn2: Level of investment in sustainable energy solutions, including solar and wind power

To facilitate the shift away from mining, this indicator focuses on assessing its smartness by investing in renewable energy sources such as solar and wind power. This criterion represents the extent to which municipalities and communities prioritise renewable energy to promote and improve energy access and security. According to the study's findings, renewable energy efforts require substantial land and resource assessments, which the municipality appears unlikely to meet, given its agricultural culture. The study's findings illustrate a solar firm seeking property on four farms that include both individual and community holdings. Participant 2 mentioned the following about this matter:

> *However, the problem with that one is that. They need much length. They need a lot of fluid, and they are not prepared to buy land. They want to listen. Moreover, our land is still. We are experiencing land scarcity due to small-scale farming in the area.*

Measuring this indicator thoroughly requires a review of municipal financial incentives, private-sector commitments, and the prospects of providing land and space financing for solar and wind projects. Furthermore, trends in research and innovation could be used to track the growth of the renewable energy industry, including advancements in renewable energy storage batteries, grid integration, and smart metering. Furthermore, the attractiveness of investment in this sector could be improved by evaluating the regulatory environment, including the implementation of policy frameworks that promote renewable energy and fair rates, among other factors. To further encourage investment, universal acceptability, community involvement, and stakeholder perception and engagement should be considered. The matters mentioned above are closely related to "ISO 7.2 - Percentage of energy derived from renewable sources."

4.4.2.3.5.2 Sub-domain 2: Solid waste

Municipal solid waste is a common name for waste that is no longer usable and does not provide economic value to its owner, which is classified into three categories: solid, liquid, and gaseous (Rajesh, 2019).

4.4.2.3.5.2.1 SEn3: The percentage of identified potential solutions to minimise waste

When evaluating the proportion of recognised viable solutions to eliminate waste, the following elements are considered: improved waste management practices, waste generation reduction initiatives, research, and innovation. This indicator aligns with the "ISO 16.1 to 16.6 - Waste solutions." It considers solutions such as minimising waste, recycling materials, and promoting environmental protection through proactive efforts by the municipality, public-private partnerships, and communities to develop and execute such programs. This criterion is used to evaluate a range of recognised efforts, including solid waste recycling and composting programs, waste-free policy frameworks, and waste-to-energy technologies. Data from surveyed communities, private waste management enterprises, and the municipality can provide qualitative and quantitative insights into the degree to which these solutions are implemented at the community level. Furthermore, adopting environmentally friendly, recyclable materials, such as cardboard, certain plastics, and glass containers, reduces waste and provides quantifiable indicators of the solutions' impact. While research and innovation institutions play a significant role in developing successful waste-reduction technologies and solutions, collaboration between the public and commercial sectors should not be overlooked. As such, the evaluation of this indicator should primarily focus on the proportion of implemented waste reduction methods, which undoubtedly helps policymakers identify gaps in the waste management system and aid improvement where necessary. Continuous adaptation of waste-reduction methods ensures that creative ideas are generated and deployed to enhance environmental health and build a cleaner, healthier society.

4.4.2.3.5.2.2 SEn4: Level of investment to support plans to explore the use of waste-to-energy as a viable solution

This indicator evaluates research and innovation in waste-to-energy technologies, which include various approaches for producing heat and power from waste. As part of the framework, this indicator seeks to track several aspects of waste-to-energy to assess the degree of investment initiated by the municipality. This indicator assesses municipal initiatives for recycling solid waste into power using data such as commercial garbage, old tyres or non-recycled tyre components, sanitary waste, food waste, and agricultural residue. The study findings indicated that waste-to-energy and gas technologies have the potential to reduce landfill trash. Furthermore, techniques to address this variable, which impacts energy extraction efficiency, are measured. This initiative is part of community services, where waste is managed through established processes. Participant 2 states the following on this matter:

> *Yeah, they are coming, but mostly that one is. Under community service because we have. They have had a landfill-sized* (Participant 2).

Furthermore, promoting waste-to-energy technologies requires robust policy frameworks to govern waste segregation, energy purchase agreements, and tax incentives for green technology investments, among others, as these regulations affect the attractiveness and investment in municipal waste-to-energy projects. The success of waste-to-energy solutions is based on the insights gained via cooperation between research institutes and technology businesses. Participant 2 stated that the municipality is open to partnerships and presented an example in which, if a corporation such as "Tetra" sought a partnership, it ideally ought to operate inside the municipality to align with local plans and maximise the benefits of the relationship:

However, for now, if they decline, this is the company that you will supply with this waste. We usually say it is better if those people operate within our municipality, as with this Tetra (Participant 2).

In addition, a more comprehensive understanding of the broader impact of these investments can be gained by assessing environmental and social factors, such as landfill waste reductions, reduced pollution, encouraging greenhouse gas emissions, a cleaner municipality, and community involvement through public engagement. The activities mentioned above relate to the "ISO 16.5 and 16.6 - Percentage of city waste treated from waste-to-energy plants and biologically treated for use as gas" indicator.

4.4.2.3.5.2.3 SEn5: The proportion of negative impact caused by illegal dumping within the municipality

This indicator is evaluated based on the municipality's ability to address the adverse effects of unlawful dumping and its environmental impact. "ISO 16.7 and 16.8 - Percentage disposed of in open dump and by other means" is closely related to this indicator. This indicator assesses the impact of illegal waste disposal on public health, sanitation, and general citizen welfare. This criterion cannot be adequately measured until data on the capacity and types of illegally deposited garbage, the recurrence rate, and the dumping locations have been collected. This information may be gathered from waste management reports, municipal governments, environmental monitoring systems, and community reports. Equally essential is consideration of harmful elements, such as environmental contaminants, soil deterioration, and water-source pollution, all of which are significantly impacted by illegal dumping. To reduce illegal dumping, community awareness efforts should be strengthened alongside reliable law enforcement measures. Waste management programs and initiatives also need to be evaluated to better understand their impact. Moreover, public feedback on waste management best practices and the effectiveness of existing processes in preventing illegal dumps will provide valuable insights into citizens' perspectives. By evaluating this indication, the municipality can mitigate the negative impacts of illegal dumping, enhance public health, and promote an environmentally friendly atmosphere.

4.4.2.3.5.2.4 SEn6: Satisfaction level of citizens with municipal waste management and collection scheduling

Measuring citizens' satisfaction with municipal waste management and collection schedules, as well as the efficiency, reliability, and accessibility of these services, includes assessing public perceptions of the efficacy of waste disposal services. This indicator measures the proper timing of regular waste collection, ensuring the municipality meets residents' waste management needs and provides essential information. The critical interaction with citizens to collect data, such as the adequacy of waste disposal facilities, the waste management department's responsiveness to challenges, waste collection frequency, and street cleanliness, is critical in assessing residents' satisfaction levels in this indicator. Equally crucial is data collection that can help the municipality detect service gaps, such as irregular garbage collection schedules, which result in delays and missed collections. Similarly, to effectively measure this indicator, responding to and assessing public complaints, including the time it takes the municipality to respond to and resolve waste management concerns, can indicate areas where service provision is insufficient. Furthermore, this indicator should evaluate best practices in waste management, such as collection credibility, consistency, efficiency, and effectiveness. Insights from this indicator evaluation could significantly assist the municipality in maintaining and enhancing waste management infrastructure, resulting in increased public trust and satisfaction and a cleaner, healthier environment. The above values correspond to "ISO 16.1 - Percentage of population with regular solid waste collection."

4.4.2.3.5.3 Sub-domain 3: Sanitation

4.4.2.3.5.3.1 SEn7: The percentage of sewer networks and wastewater treatment works

The sewage networks and wastewater treatment industries confront various issues, including failure to reach mandatory targets, budget overruns, schedule delays, and insufficient sustainability. As a result, to evaluate the state of wastewater management systems, the municipality must invest extensively in programs that construct and maintain wastewater treatment networks. This indicator corresponds to the "ISO 22.1 - Percentage of treated wastewater being reused." To assess this indicator, the reliability of sewer networks and the capacity of associated treatment facilities to serve a proportion of the population are considered, particularly to ensure that sewage and wastewater treatment processes meet health and environmental requirements. To evaluate this indicator, data on population size, including the total number of functional sewage systems and wastewater treatment networks, should be gathered and analysed. Importantly, an extensive review of how sufficient sewer systems reach neglected areas within the municipality that might pose a health hazard or environmental concern due to inadequate sewage infrastructure should be conducted. The evaluation of this indicator cannot be complete until environmental regulations that concern compliance and operational effectiveness of wastewater treatment network operations are assessed to ascertain that wastewater network treatment performance is of excellent quality and meets acceptable standards. Furthermore, gathering community perspectives on the percentage of pollutants and contaminants removed from wastewater to protect human health and the environment whenever treated wastewater is discharged back into the piped water system provided for human consumption provides insight into the effectiveness of the treatment system. Similarly, the necessity of regular treatment system maintenance cannot be overstated; hence, maintenance schedules combined with new technologies, categorised as physical, chemical, and biological, can improve the performance of sewage networks. It is crucial to assess the duration that it takes the municipality to resolve a sewage blockage, as well as the frequency of such incidents. The overall assessment of this indicator is to ensure that the municipality provides a safe, effective, efficient, and credible wastewater management system, creating a cleaner, healthier environment for communities.

4.4.2.3.5.4 Sub-domain 4: Water

The need to measure water arises from the need to assess the effectiveness of a smart environment dimension relative to other domains and, more importantly, to identify smart indicators that the municipality lacks in targeting for improvement.

4.4.2.3.5.4.1 SEn8: The share of people in the municipality who have access to piped water

Water dependability measures how easily households can access water when needed. Such criteria are crucial in establishing the settlement's suitability while also enhancing human well-being. This indicator evaluates not only access to clean water but also the reliability and availability of municipal piped water systems. Essentially, this indicator represents availability while also emphasising the importance of the health, safety, and, most significantly, the clean quality of the piped water supply infrastructure in individuals' lives. The assessment of this criterion involves considering the geographical coverage of water systems within the municipality, using data acquired from the total population and the percentage of people linked to piped water infrastructure. Moreover, the reliability of the water supply is crucial to the municipality's smartness, as unreliable water sources put residents at risk. Additionally, by measuring this indicator, insights can be drawn to help understand the issues communities confront, including geographic areas, piped water access costs, and the overall affordability of piped water service. Other significant factors that contribute to measuring this indicator include evaluating the performance of infrastructure, such as water treatment facilities, implementing water conservation measures, and assessing the extent to which its capacity meets community demands and expectations. By examining this indicator, the underserved population can be identified, and the municipality can use the information to plan and expand the necessary piped water access infrastructure in the region lacking it. The measurements, as mentioned earlier, reflect "ISO 23.1 - Percentage of population with potable water supply service," implying a close relationship to this indicator.

4.4.2.3.5.4.2 SEn9: The municipality coverage of smart water meters

The smart water meters incorporate best practices for water management, efficiency enhancement, and smart monitoring of water consumption. This indicator assesses the extent to which the municipality has adopted these technologies. This indicator matches that of the "ISO 23.3 and 23.4 - Percentage of city buildings and water distribution monitored by smart meters." In addition, its capacity to collect real-time data on water use provides the following benefits: reduced water waste, more accurate invoicing, and less water leakage. This statistic is calculated by comparing the total number of smart meters deployed to the total number of houses with traditional water meters. Furthermore, when measuring the functionality, effectiveness, and efficiency of smart water meters, the following features should be considered: data collection accuracy, smart meter acceptance, and advanced anomaly detection, such as overuse or leaks. Similarly, evaluation cannot be completed without measuring the benefits of smart water meters, which provide additional insights into the impact of this technology, including cost-effectiveness and advanced water protection, resulting in increased customer satisfaction and confidence in the municipality's ability to provide more accurate and transparent billing.

4.4.2.3.5.4.3 SEn10: Level of satisfaction with functional water distribution networks

The municipality's vital infrastructure, including the quality of water distribution networks, their dependability, and accessibility, is an essential factor in determining the level of satisfaction with operating water distribution indicators. This indicator is deemed strongly linked to "ISO 23.3 - Percentage of city water distribution monitored by smart meters." Residents seek satisfaction from this indicator, which includes an effective functional water distribution network capable of supplying a constant, clean, safe, and healthy water supply for human use. Furthermore, this criterion may be tested using real information gathered by asking residents for their feedback and statistics based on their degree of satisfaction with distribution network features such as water availability, water pressure, and drinking water purity. Furthermore, the efficiency and reliability of water distribution networks are objectively evaluated using data on the frequency and duration of repairs for water outages and pipe breaks, among other factors. Likewise, communication and maintenance are essential components to examine when evaluating this indicator of satisfaction, including the level of response to restoring the impacted infrastructure and the efficacy of alerting the community about service disruptions. Similarly, continuous evaluation of how the municipality responds to infrastructure concerns, particularly their responsiveness and commitment to repair, is vital to ensuring the sustained quality of service delivery to people. Moreover, insights from this indicator's assessment may help the municipality resolve service gaps and improve overall satisfaction with water distribution networks.

4.4.2.3.6 Domain 6: Smart Mobility

The last criterion of the framework is smart mobility. The effective management of mobility is a significant challenge in a municipality, and the design of smart mobility systems requires the efficient assessment of environmental and economic impacts. The proposed framework should evaluate municipal smartness in terms of accessibility, ICT development, and sustainable models, all of which are part of an integrated transportation plan. Specifically, since the municipality accommodates all groups of people within its borders, the plan incorporates three critical domains: local and international accessibility, smart and green transportation, and sustainable and innovative transport systems, all of which are assessed through the framework.

This domain has one subdomain and two must-have critical indicators (*SM-T-IND1 and SM-T-IND2*), which are discussed as follows:

4.4.2.3.6.1 Sub-domain 1: Transport Management

This criterion assesses the smartness of the municipality's resources in the integrated transport management system sector. These resources refer to the actions and tools provided by municipal authorities for the following.

4.4.2.3.6.1.1 SM1: Satisfaction with the integrated transport plan to enhance transport efficiency

The study findings reported that the municipality is exploring the implementation of an intelligent public transport system as part of its comprehensive transportation and infrastructure plans. This criterion measures procedures in place to implement a sustainable transport system, the effectiveness of its accessibility, and safety. In addition, this indicator assesses the integrated transport plan's capacity to meet the population’s fundamental needs, such as reducing traffic congestion and fostering faster, greener, and more affordable transportation options for society. The evaluation of this criterion cannot be completed without data from the following sources: community engagement and qualitative and/or quantitative feedback from residents, commuters, businesses, and the municipality. Through analysis, insights into citizens' satisfaction with the reliability, accessibility, and, importantly, affordability of the transport system are drawn. Additionally, determining how efficient integrated plans are by evaluating subsequent data, namely travel times, public transportation punctuality, and the availability of alternative modes of transport such as carpooling, car-sharing, on-demand ride services, and bicycle commuting, among others, should be conducted. Evaluating initiatives designed to revitalise critical infrastructure along key transport routes, aligned with efforts to modernise the overall transport framework, also contributes to satisfaction with the implementation of the transport plan, thereby enhancing the municipality's smartness. Similarly, an integrated transport plan is limited if it does not accommodate smart mobility innovations for individuals, such as being ICT-enabled. For this reason, reducing traffic-related issues by incorporating emerging technologies, such as hybrid electric vehicles and self-driving cars, and measuring their effectiveness will provide insights into the transport plan's effectiveness in improving transport efficiency. Regularly evaluating this indicator can provide the municipality with invaluable insights to refine its transport policies, address commuter concerns, and ultimately enhance the overall efficiency of its transportation systems. Activities related to this indicator firmly match those of the "ISO 19.8 - Transportation profile indicators."

4.4.2.3.6.1.2 SM2: Satisfaction rate with regulatory compliance for public transport systems

The study's findings demonstrated a commitment to modernising public transport systems by evaluating regulatory processes to ensure that any modifications align with municipal intentions and industry standards. Among other things, ensuring satisfaction in the transportation business requires the system to be safe and dependable and to operate under ideal road conditions, including transport providers adhering to the following regulations: commuter safety, operating permits, and excellent customer service, all of which this indicator measures. This criterion aligns with the "ISO 19.8 - Transportation profile indicators," which links it to this indicator. As a result, protocols must be regulated; this indicator evaluates regulatory action in the transport directorate by collecting data on public vehicle safety, adherence to stipulated routes, transparent fare negotiation, and accessibility for people with disabilities to the satisfaction of the community within the municipality. Furthermore, consistent analyses are required to determine whether regulatory standards are being met by collecting detailed data on incidents, various types of accidents, or complaints about noncompliance, such as overcrowding, speeding, poor vehicle maintenance, or traffic bylaw violations. The objective measures of an effective transportation system operating within a regulatory framework should include implementing regulatory measures, such as inspections and penalty fees for non-compliant vehicles. It is critical to assess the effectiveness and efficiency of regulations governing transportation safety that promote and encourage a clean, healthy environment, such as setting contaminant restrictions, limiting public transportation costs, and ensuring driver license compliance. To ensure compliance is monitored and maintained, this indicator should be regularly evaluated by the municipality.

4.4.3 Layer 3: The Smartness Measurement

This last layer of the proposed framework comprises two critical components that measure the municipality's level of smartness: ***Assessment Data*** and ***Smartness Status Levels***. This assessment framework would enable a municipality to measure its current smartness and compare that against its ideal smartness, all within the confines of its long-term vision.

4.4.3.1 Assessment Data

Various data sources must be collected at the local level to enable effective measurement of a municipality's smartness. This framework aims to accurately measure and reflect the current level of smartness of the target municipality. It is based on a combination of the survey of indicators from the IDP implementation, StatsSA indicators, and Census 2022 themes released in October 2023. Based on the survey results, each content provision is heuristically analysed and scored on a scale from lowest to highest, as shown in Table 4.4.

4.4.3.2 Municipality Smart City Levels

A detailed smartness matrix that highlights the five distinct levels of a municipality's advancement is presented in Table 4.4. This table demonstrates the critical role of each dimension in categorising the municipality's overall smartness. Besides, this table provides a comprehensive reference for understanding how a municipality can advance its capabilities, infrastructure, and services in line with smartness principles. Thus, for a municipality to properly plan and implement smartness initiatives, this matrix is suitable for measuring progress and finding chances for improvement at each level.

Table 4.4: Municipality Smart City Levels Matrix, adapted from Aljowder, Ali and Kurnia (2023)

Dimension	Level 1: Basic	Level 2: Developing	Level 3: Intermediate	Level 4: Advanced	Level 5: Innovative
Smart Governance	Basic administrative capacity and manual processes	Digitised record-keeping and basic e-government services	Online public services and participatory tools were introduced	Advanced e-governance and integrated decision-making	Technology-driven governance and predictive analytics for decision-making
Smart Economy	Dominated by traditional industries with low innovation	Emerging local industries with basic incentives for SMEs	Technology hubs are established with growing innovation ecosystems	Digital economy flourishing with strong innovation networks	Global competitiveness with widespread use of technology and IoT
Smart People	Low literacy and digital skills, with limited citizen engagement	Basic ICT education programs and occasional public forums	Citizen-driven projects and increasing digital fluency	Active civic technology communities with high digital inclusion	Co-creation of policies with outstanding skills and talent
Smart Living	Slight infrastructure for well-being and limited safety	Improved health, housing, and safety initiatives	Smart infrastructure, like smart meters and energy grids	High-quality, integrated services for health, housing	Fully connected, enhanced living ecosystems
Smart Environment	Poor waste management with reliance on non-renewable energy	Basic environmental policies and initial green projects	Renewable energy adoption and better waste management	Smart environmental monitoring and significant renewables use	Carbon neutrality with advanced environmental technology and IoT
Smart Mobility	Limited public transport and poorly maintained roads	Basic improvements to transport infrastructure	Introduction of intelligent traffic systems to improve public transit	Fully integrated, multimodal smart transport networks	Autonomous transport with zero-emission systems
Overall Smartness	Traditional methods with minimal integration of innovative solutions	Use of technology in basic functions, emphasising infrastructure improvement and preliminary adoption of smart solutions	Beginning of digital transformation, with communities actively participating and benefitting from smarter solutions	A robust ecosystem, with integrated smart systems and increased community participation	Extensive innovation, advanced technologies, and sustainable practices to provide exemplary services

4.5 Summary

This chapter presented the critical components of the proposed framework. The deliberation of the distinct components of the framework is achieved through three different critical layers. The key technological components of SAF that facilitate the effective assessment processes of the framework are Smart City Domains, Smartness Ideal, and Smartness Assessment. Smart City Domains provides a universal framework, as proposed by Giffinger *et al*. (2007), that also highlights the municipality's main functions; this layer serves as the basis for adapting the framework. The Smartness Ideal provided the context that enabled the realisation of a vision-based initiative through the municipal IDP. This need-based initiative laid the foundation for the framework by conducting interviews with municipal officials and using StatsSA data on municipal residents. Lastly, a critical component of the Smartness Ideal, which presents the essential part of the framework, was drawn from the need-based and plan-based visions. The last main component of the framework was the Smartness Assessment. This component elaborated on data collected from a combination of surveys and indicators for IDP implementation, and from StatsSA indicators, to test the framework. This chapter concluded with a detailed overview of the five distinct levels of municipal smartness.

Chapter 5 focuses on the detailed evaluation of the framework utilising the data described in this chapter.

CHAPTER FIVE – SMARTNESS ASSESSMENT FRAMEWORK EVALUATION, MATJHABENG MUNICIPALITY

5.1 Introduction

This chapter evaluates the SAF using data from IDP implementation and StatsSA indicators. StatsSA data, on the one hand, is primarily quantitative, consisting of numerical values that can be measured and counted. On the other hand, IDP data, which is typically considered qualitative, often includes demographic statistics (quantitative). For this evaluation, the study employed a Census 2022 dataset from StatsSA, as it was found to be more complete and its representation was clearly and neatly presented (Statistics South Africa, 2022). Chapter 5 focuses on the detailed evaluation of the framework utilising the data described in this chapter.

5.1.1 Municipality Demographic Information

In this research, the 2022 Census data, published on StatsSA's national database, was acquired in line with the relevant official statistics publication calendar coordinated by StatsSA. The census dataset included male and female participants. 48% of the participants were male, and 52% were female.

5.1.2 Utilising StatsSA and Integrated Development Plan Data

This section shows how the survey data meets part of research objective four: to use the case study of a waste management and reporting system to evaluate the framework developed (to be discussed in Chapter 6). Thus, the study quantitatively analysed respondents' data at the municipal level on Smart Governance, Smart Economy, Smart People, Smart Living, Smart Environment, and Smart Mobility in municipal development projects to determine the extent to which these services are available in and around municipal areas. This section, layer two, uses the Municipality Smart City Ideal, a critical component of the framework. This component continues by analysing six domains (i.e., top-down and bottom-up approaches) used to measure municipal smartness in the provision of community services. Here, the framework is assessed based on two critical data components, IDP and StatsSA, located in the subcomponent Assessment Data within layer three, Smartness Measurement. These two secondary data sources are essential in testing the workability of the framework.

Next, the indicator data were collected from primary and secondary sources in the data collection phase, and CSF ratios and maximum values were calculated using the formulas determined in section 5.3 of this Chapter. However, it is crucial to recognise that secondary data sources lack the detailed information necessary for a comprehensive evaluation of the framework. This gap includes, but is not limited to, innovative meter water management, waste-to-energy initiatives, and smart skills development. Currently, these elements are merely part of the municipality's 2050 vision and are recorded in the IDP, with no concrete implementation. For instance, Kuzwayo (2020) highlights a similar issue: municipal IDPs often lack dedicated sections for gender mainstreaming. Hence, the study is also underpinned by relevant literature to fully assess the municipality's level of smartness.

Table 5.1 outlines the method of computation used to measure secondary datasets for values provided for each mentioned indicator across the various domains of the framework, starting from Table 5.2.

Table 5.1: Secondary Data Computation Methods for Indicator Values

Subdomain for Indicators	Method of computation
Finance, Governance, Telecommunication, Urban Planning, Community Participation, and Public-Private-Partnership	A questionnaire with a 5-point Likert scale (1-very low, 2-low, 3-moderate, 4-high, and 5-very high) is used to test the level of participation from the objective viewpoint: 1. Level of citizen involvement in municipal finances and expenditure agreements, 2. Supervision and criticism of the performance of municipal management, 3. Membership in social foundations and organizations, 4. Level and diversity of cooperation in m planning/budgeting/ procurements 5. Participation in public-private-participation planning designs and agreements.
Jobs, Innovation, and SMEs	Calculate the percent of jobs created, innovation initiatives, and sme's supported by the municipality.
Education	The computation is based on the proportion of households with access to public Education.
Housing, Population Conditions, and Safety and Security	Households (H) = $100\ X\ \frac{No.people\ living\ in\ H}{City\ population}$ Calculate the percentage of citizens who were subjected to criminal activities.
Energy, Waste, Sanitation, and Water	The computation depends on the proportion of households that have access to safe water, access to improved sanitation facilities, access to solid waste

Subdomain for Indicators	Method of computation
	management services, and access to modern and renewable energy.
Transport	The computation depends on the proportion of households that have access to public transport and roads

5.1.2.1 Smart Governance

From the quantitative analysis, the best services for implementing municipal development indicators include Finance, Governance, Telecommunications, Urban Planning, Community Participation, and Public-Private Partnership, as presented in Table 5.2.

The statistics reveal a mixed landscape of technological infrastructure and digital readiness among municipal residents and staff. Although the municipality aims to support citizens in developing basic job skills, the budget remains a considerable challenge (10%); hence, it relies heavily on SETAs, which are entrusted with this responsibility. While the level of ICT infrastructure enabling remote service payments stands at 70%, only 44% of municipal staff have received training to keep up with technological advancements. Despite efforts to modernise operations, data management improvements remain at 1%, signalling a gap in digital transformation. Additionally, only 19% of municipal households own computers, and 30% have broadband internet access, which may limit full digital integration, according to the StatsSA 2022 Census. On the governance side, planning documents such as the IDP have been partially implemented (60%), and the regulatory framework not entirely aligned with government laws (71%). Furthermore, roadshows aimed at information sharing and distribution have achieved (51%) participation, demonstrating strong community engagement. As reported in the IDP, the municipality's collaboration with the private sector on repurposing initiatives has a satisfaction rating of 54%. This, therefore, indicates a moderate level of approval, with opportunities to enhance cooperation and effectiveness.

Table 5.2: Finance, Governance, Telecommunication, Urban Planning, Community Participation, and Public-Private Partnership Sub-domain

Finance, Governance, Telecommunication, Urban Planning, Community Participation, and Public-Private-Partnership Sub-domain			
Sub-domain	**Indicator code**	**Indicator**	**%**
Finance	SG1	SETAs' budget supports basic job skills development	10
	SG2	Level of ICT infrastructure for remote service payments by municipal residents	70
Governance	SG3	Staff training is provided to keep up with technological advancements	44
	SG4	Modernised operations through improved data management	1
Telecommunication	SG5	Proportion of computers in municipal households	19
	SG6	Broadband internet access percentage in households	30
Urban Planning	SG7	Implementation rate of planning documents like the IDP	60
	SG8	Regulatory framework aligned with government laws	71
Community Participation	SG9	Percentage of roadshows organised to share and distribute information	51
Public-Private-Partnership	SG10	Satisfaction with collaboration with the municipality on repurposing initiatives	54

Source: Statistics South Africa (Community Survey, 2022) and Integrated Development Plan (2024)

5.1.2.2 Smart Economy

From the quantitative analysis, some of the best services available for implementing municipal development indicators include *Jobs, Innovation,* and *SMEs*.

StatsSA's Census 2022 figures in Table 5.1 highlight key efforts in youth career promotion and economic partnership. Reflecting the rising emphasis on diverse career prospects, the StatsSA Census 2022 found that a significant 56% of projects promote alternative career routes for young people. Furthermore, 28% of prospects show a strategic partnership gap, according to the IDP. To encourage entrepreneurial innovation, 56% of platforms for proposing fundable ideas (imbizos) have been built. Furthermore, the IDP reports that 50% of investment centres fund research and development, demonstrating a commitment to long-term economic growth. Besides, the most recent municipal annual report stated that 81% of people obtained apprenticeships and learnerships through municipal interventions, suggesting effective local government participation in skills development. Because two of the data sources examined in this analysis did not have information on the transformation percentage of abandoned mine shafts, 2% of the data sources met this criterion. Marais, van Rooyen, Nel, and Lenka (2017) confirm the lack of data by stating that the Matjhabeng Municipality's IDP does not address mine closure but instead mentions mining mitigation and reconstruction efforts undertaken by mines through social and labour plans or corporate social responsibility programs. Meanwhile, emphasising the significance of public-private collaboration in job development, 60% of local business partnerships are dedicated to boosting employment prospects, according to municipal annual reports. This data demonstrates tremendous progress while also suggesting areas where additional investment and collaboration could further enhance this effect.

Table 5.3: Jobs, Innovation and SMEs Sub-domain

Jobs, Innovation, and SMEs Sub-domain			
Sub-domain	**Indicator code**	**Indicator**	**%**
Jobs	SE1	Career paths for youth	56
	SE2	Opportunities based on collaboration	28
	SE3	Platforms for presenting fundable ideas (*imbizos*)	56
	SE4	Centres supporting research and development efforts	50
Innovation	SE5	Individuals connected to apprenticeships and learnerships	81
	SE6	Transformation percentage on abandoned mine shafts	2
SMEs	SE7	Partnership with local businesses	60

Source: Statistics South Africa (Community Survey, 2022) and Integrated Development Plan (2024)

5.1.2.3 Smart People

From the qualitative analysis, some of the best services available for implementing municipal development indicators include Education, as presented in Table 5.4.

According to StatsSA data, a review of education and skills development statistics shows that 38% of the population has attained secondary education, while only 9% have pursued tertiary education. In efforts to enhance workforce skills, 70% of employees have utilised SETAs for professional development, the IDP reported. Furthermore, the IDP noted that 60% of respondents expressed satisfaction with the Skills Levy, indicating a generally positive perception of the initiative's role in funding and improving skills training programs. These figures highlight both progress and areas for potential growth in education and workforce development.

Table 5.4: Education Indicators

Education Sub-domain		
Indicator code	**Indicator**	**%**
SP	Population with secondary level	38
SP	Population with a tertiary level	9
SP	SETAs to enhance skills	70
SP	Satisfaction with the Skills Levy	60

Source: Statistics South Africa (Community Survey, 2022) and Integrated Development Plan (2024)

5.1.2.4 Smart Living

The fourth dimension is smart living, with sub-domains including: *Housing, Population Conditions,* and *Safety and Security*.

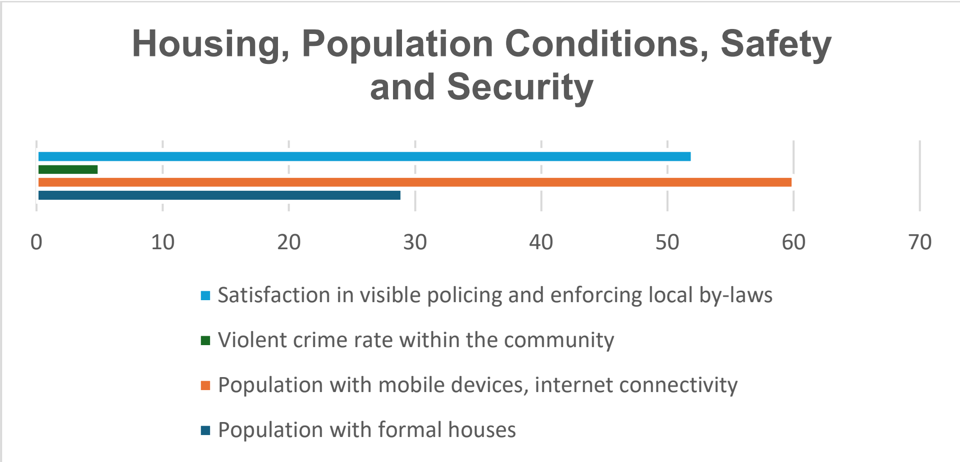

Figure 5.1: Housing, Population Conditions, and Safety and Security Sub-Domains. Source: Statistics South Africa (Community Survey, 2022) and Integrated Development Plan (2024)

Figure 5.1 demonstrates the significant challenges of accessing suitable shelter and infrastructure; the statistics suggest that only 29% of the population lives in official dwellings. Despite housing limitations, 60% of the population has access to mobile devices and internet connectivity. In summary, this shows that while housing construction is slow, technical access is growing, enabling digital inclusion, remote employment, and internet access, which might help overcome socioeconomic divides. According to Sesele and Marais (2023), Matjhabeng has the highest crime rate among South African cities of comparable size, with a 5% rise per 100,000 inhabitants. The area recorded 5,077 reported crimes across various categories, surpassing comparable cities and even some metropolitan areas. Regarding law enforcement visibility and bylaw enforcement, the 52% statistic suggests that nearly half of the population may feel they are inadequate, potentially pointing to concerns about response times, patrol presence, and enforcement consistency, among others.

5.1.2.5 Smart Environment

From the qualitative analysis, the best services for implementing municipal development indicators include *Energy, Waste, Sanitation,* and *Water*.

Table 5.5: Energy, Waste, Sanitation, and Water Sub-domain

Energy, Waste, Sanitation, and Water Sub-domain			
Sub-domain	**Indicator code**	**Indicator**	**%**
Energy	SEn1	Provision and installation of street lighting	2
	SEn2	Sustainable energy solutions, including solar and wind power	81
Waste	SEn3	Potential solutions to minimise waste	46
	SEn4	Waste-to-energy as a viable solution	1
	SEn5	Negative impact of illegal dumping within the municipality	41
	SEn6	Satisfaction with municipal waste management and collection	46
Sanitation	SEn7	Sewer networks and wastewater treatment works	54
Water	SEn8	Access to piped water	51
	SEn9	Smart water meters	1
	SEn10	Functional water distribution networks	38

Source: Statistics South Africa (Community Survey, 2022) and Integrated Development Plan (2024)

The statistics demonstrate significant variations in service delivery across municipalities, highlighting areas of strength and concern. While sustainable energy options like solar and wind power have an implementation rate of 81%, the provision and installation of street lighting remain severely low at only 2%, as noted in the IDP. Not only does waste management give a mixed image, with 46% expressing satisfaction with municipal waste collection, but the exact number identifies viable waste reduction methods, indicating an opportunity for improvement. The investment in waste-to-energy as a viable solution stands at 1%. Moreover, not only did the IDP report illegal dumping as a cause of a negative impact within the municipality wards, reaching a level of 41%, but it also highlighted the urgent need for stricter waste management policies and enforcement measures. Fandaleki (2024) reported that households without disposal choices are obliged to dump rubbish in open areas, worsening the illegal dumping situation and indicating that the municipality's attempts to solve the crisis are ineffective. On the one hand, sewage networks and wastewater treatment plants run at a modest 54%, while on the other hand, access to piped water is at 51%, according to StatsSA. However, the IDP found that installation and upgrading of prepaid water meters are only now at the tender stage (1%), and just 38% of water distribution networks are operational, highlighting inefficiencies in water infrastructure. This data highlights the importance of focused investments in water management, street lighting, and waste reduction to improve overall service performance and sustainability.

5.1.2.6 Smart Mobility

From the qualitative analysis, some of the best services available for implementing municipal development indicators include *Transport*.

Table 5.6: Transport Indicators

Transport Sub-domain		
Indicator code	**Indicator**	**%**
SM1	Integrated transport plan to enhance transport efficiency	5
SM2	Regulatory compliance for public transport systems	10

Source: Statistics South Africa (Community Survey, 2022) and Integrated Development Plan (2024)

The available data in Table 5.6 indicate that an integrated transport plan aimed at enhancing the efficiency of the municipality's transport network to provide citizen satisfaction stands at 5%. Similarly, the public transport system's compliance with regulations is at 10%. As a result, public approval of efforts to improve transportation networks and enforce regulations remains relatively low, as shown in the figures.

5.1.2.7 Percentage Values for All Domains

Table 5.7: Indicators' Percentage Values for Different Domains

Ind	SG	Ind	SE	Ind	SP	Ind	SL	Ind	SEn	Ind	SM
SG1	10	SE1	56	SP1	38	SL1	52	SEn1	2	SM1	5
SG2	70	SE2	28	SP2	9	SL2	5	SEn2	81	SM2	10
SG3	44	SE3	56	SP3	70	SL3	60	SEn3	46		
SG4	1	SE4	50	SP4	60	SL4	29	SEn4	1		
SG5	19	SE5	81					SEn5	41		
SG6	30	SE6	2					SEn6	46		
SG7	60	SE7	60					SEn7	54		
SG8	71							SEn8	51		
SG9	51							SEn9	1		
SG10	54							SEn10	38		

Table 5.7 demonstrates the values drawn from the six domains of the framework. The values accurately reflect the indicators per the key domains mentioned. As mentioned earlier, these values were drawn from the municipal IDP and StatsSA alike. Distinct tables were critically analysed, the values presented, and the methods of collection detailed from the sources mentioned. Notably, this data matrix is presented as percentages, clearly showing different numbers of indicators per domain. Smart governance (SG) comprises 10 indicators, each with a different rate. The smart economy (SE) has seven indicators relevant to this domain. Smart people (SP) and smart living (SL) alike have the same number of indicators, totalling four. Like smart governance, the smart environment (SEn) domain also has 10 indicators. The last dimension of this framework is the smart economy (SM), represented by two indicators, the only dimension with few indicators compared to the others.

Indeed, the assessment of a particular domain is significantly determined by indicators. In this framework, it is notable that the municipality's level of smartness cannot be calculated based on a single domain; all domains must be assessed. This is how the developed model demonstrates its consistency.

5.1.2.8 Normalisation and Scaling

The most common approach to analysing smart city concepts involves using indicators, each with its own measurement scale. As a result, the use of secondary data from StatsSA, presented as indicators in percentages in Table 5.7, may not be a statistically preferred data source for further computation of the study's desired outcomes. Hence, a more sophisticated approach to data preparation for analysis was required. For this reason, the study sought a reputable method to prepare and ensure data compatibility. Nominalisation became the preferred choice for such a process. This scaling process converts indicators' diverse score units into values usually ranging from 0 to 1, with 1 preferred over 0. Furthermore, Table 5.8 shows all min-max values computed that meet the recommendations.

Table 5.8: Normalised Indicators' Values for Different Domains

Ind	SG	Ind	SE	Ind	SP	Ind	SL	Ind	SEn	Ind	SM
SG1	0,1125	SE1	0,6875	SP1	0,4625	SL1	0,6375	SEn1	0,0125	SM1	0,0500
SG2	0,8625	SE2	0,3375	SP2	0,1000	SL2	0,0500	SEn2	1,0000	SM2	0,1125
SG3	0,5375	SE3	0,6875	SP3	0,8625	SL3	0,7375	SEn3	0,5625		
SG4	0,0000	SE4	0,6125	SP4	0,7375	SL4	0,3500	SEn4	0,0000		
SG5	0,2250	SE5	1,0000					SEn5	0,5000		
SG6	0,3625	SE6	0,0125					SEn6	0,5625		
SG7	0,7375	SE7	0,7375					SEn7	0,6625		
SG8	0,8750							SEn8	0,6250		
SG9	0,6250							SEn9	0,0000		
SG10	0,6625							SEn10	0,4625		

There are different types of scaling methods, such as standardization (Z-score), Robust Scaling, and Min-Max Scaling. The Min-Max normalization method linearly transformed the original data, balancing value comparisons between the pre-transformed data in Table 5.7 and the post-transformed data (Shantal, Othman, & Abu Bakar, 2025). The scaled values are computed using the following equation:

$$X_{scaled} = \frac{X - X_{min}}{X_{max} - X_{min}}$$

Equation 1

Where $\mathbf{X_{new}}$ is the new value from the normalized results, **X** is an old value, $\mathbf{X_{max}}$ equals the maximum value in each domain dataset, and $\mathbf{X_{min}}$ equals the minimum value in each domain dataset. Using SG1 as an example, a normalised value of 0,1125 was calculated as follows:

All Values (37 indicators total):

[10, 70, 44, 1, 19, 30, 60, 71, 51, 54, 56, 28, 56, 50, 81, 2, 60, 38, 9, 70, 60, 52, 5, 60, 29, 2, 81, 46, 1, 41, 46, 54, 51, 1, 38, 5, 10]

Minimum Value: min = 1

Maximum Value: max = 81

Range: R = max - min = 81 - 1 = 80

SG1: = (10 – 1) / 80 = 9 / 80 = 0,1125

Equally, the other indicators in different domains were all calculated using the same procedure; the results are shown in Table 5.8.

5.1.2.9 Trapezoidal Fuzzy Synthetic Evaluation

Trapezoidal membership can be applied to both raw percentages and normalised data; however, to achieve high-quality results, normalised data is preferred. In fuzzy logic, a trapezoid membership function uses four parameters (a, b, c, d) that give the location of the fuzzy membership function, where a < b < c < d represent the degree to which an element belongs to a fuzzy set (Narayanan & Muthusamy, 2024). For this reason, Equation 1, as the Min-Max normalisation method, was incorporated to calculate the fuzzy trapezoidal membership function. A given set of normalised data for each domain is calculated using the formula shown in Equation 2, and the corresponding results are shown in Table 5.9:

$$U_x = \begin{cases} 0, & x \leq a \\ \dfrac{x-a}{b-a}, & a \leq x \leq b \\ 1, & b \leq x \leq c \\ \dfrac{d-x}{d-c}, & c \leq x \leq d \\ 0, & x > a \end{cases}$$

$$Where: a, b, c \text{ and } d \text{ are given in the table below for each linguistic variable}$$

Equation 2

Table 5.9: Linguistic Variables and Trapezoidal Fuzzy Numbers

Development Level	Trapezoidal (a, b, c, d)	Scale	Description
Basic (B)	(0.0, 0.0, 0.1, 0.3)	1	Inferior development
Developing (D)	(0.1, 0.3, 0.4, 0.5)	2	Poor development
Intermediate (Im)	(0.4, 0.5, 0.6, 0.7)	3	Moderate development
Advanced (A)	(0.6, 0.7, 0.8, 0.9)	4	Good development
Innovatitve (In)	(0.8, 0.9, 1.0, 1.0)	5	Excellent development

Table 5.9 converts normalised scores to rating distributions using the following mapping rule (0-1 normalized scale):

0.0 ≤ Normalized < 0.2: High B, Moderate D

0.2 ≤ Normalized < 0.4: Moderate B, High D

0.4 ≤ Normalized < 0.6: High Im, Balanced

0.6 ≤ Normalized < 0.8: Moderate A, High In

0.8 ≤ Normalized ≤ 1.0: High A, Moderate In

Essentially, because weighting determination is based on a combination of the Equation 2 algorithm and the mapping rules outlined in Table 5.8, the trapezoidal function provides a more reliable dataset free of unit differences, thereby allowing consistency amongst the indicators (Soemarsono, Yazid, & Mardlijah, 2025). Notably, like min-max scaling, trapezoidal scaling effectively ranges from 0 to 1 for linguistic variables such as basic, advanced, intermediate, and innovative. It outshines other methods by clarifying what others find ambiguous. Its ability to structure full membership while accommodating partial membership enhances normalised input data and provides meaningful presentation.

5.1.2.10 Balancing of Indicator Weights for All Domains

The Matjhabeng IDP highlights the importance of all indicators towards the development and improvement of service delivery to the community. Amongst the essential indicators, different spheres of government, from national down to municipalities, mention education, health, safety, and basic services, among others, as indicators that belong to domains such as SL and SP, particularly. Moreover, these critical domains require much sophisticated weighting, as they address citizens' basic needs for improving the quality of life and are often rated poorly in performance, thereby causing injustice. Therefore, other weighting methods, such as entropy, can assist in standardising such indicators, thereby ensuring equal treatment in their computation (Ding, Niu, Zhou, Sun, Wang, Dong, Ding, Wu, Wen, Cui, & Xiang, 2025). Thus, entropy is another alternative that can be utilised to compute indicator weights, enabling the objective assessment of domains.

5.2 Analytic Tests

In this section, the fuzzy synthetic method is considered to evaluate smartness. This method applies the multicriteria synthetic assessment technique, which effectively captures diverse data from the framework's domain indicators, and was deemed most suitable for the following reasons: It handles vague data through its logic and converts linguistic or subjective judgments into quantifiable values. In addition, as indicated earlier, it integrates multiple criteria by synthesizing diverse indicators into a single, comprehensive evaluation index. In conclusion, it reduces evaluator bias by mathematically modelling uncertainty, thereby providing a more objective, consistent assessment.

As noted in the literature, the concept of smart cities has attracted significant attention as municipalities seek to enhance sustainability, efficiency, and quality of life through advanced technologies and data-driven decision-making (Table 5.9).

Furthermore, the multicriteria decision-making method (MCDM) is one strategy used to analyse the six domains and assess the smartness of Matjhabeng Municipality. MDCM is the recommended choice, as this research focuses on several domains that are fundamentally contradictory, each with its own set of relevant indicators, and these domains interact in their calculations, contributing to the municipality's overall level of smartness. Because the data gathered from both the IDP and StatsSA were insufficient and vague, the researcher used MCDM approaches in a fuzzy environment to reach an acceptable conclusion. In essence, it improves upon earlier frameworks by offering a more flexible, objective, and uncertainty-tolerant evaluation of smart city performance, yielding more realistic, context-sensitive insights. Because of the fuzzy capacity to utilise gathered data scores with membership functions (MF), results were allocated and the association rate was determined for each indication in the domains to be discussed later (Alakhras, Oussalah & Hussein, 2020).

This strategy enabled or facilitated making collective decisions based on the analysed data. Hence, statistically, FSE is usually regarded as one of the established methodologies to examine MCDM procedures. As a result, the previously described fuzzy MCDM technique has been applied to assess the smartness of this municipality. For the aim of this study, the relevant literature was reviewed to identify the criteria deemed appropriate for statistically measuring the smartness of this municipality, and FSE was selected accordingly at the outset of this section.

5.3 Determination of Suitable Weightings for Domains and Indicators

This section calculates perceived suitable weightings for each domain and indicators required when using FSE to determine membership function values for measuring smartness. As such, the study employed two credible secondary data sets, municipal IDPs and StatsSA, to collect data, which required testing. To ensure that the variable internal consistency and reliability are addressed, the scale's Cronbach's alpha coefficient was examined. Ahmad, Alias, Hamat, and

Mohamed (2024) argue that constructs with Cronbach's alpha coefficients of 0.700 or higher, such as questionnaires and interviews, exhibit extremely high reliability.

Table 5.10 shows the calculated indicator weights for all domains, summarised as SG (10), SE (7), SP (4), SL (4), SEn (10), and SM (2). In Table 5.12, for FSE, the MF evaluation for different indicators is estimated at the first level, and the various domains are determined at the second level simultaneously. The last level of the MF provides the overall smartness development level index of Matjhabeng.

Table 5.10: Weightings of Domains and Indicators of Matjhabeng Municipality

Indicator	Data value	Data Weight	Total Data value	Total Weight	Indicator	Data value	Data Weight	Total Data Value	Total Weight
SG			**5,0000**	**0,2847**	**SL**			**1,7750**	**0,1011**
SG1	0,1125	0,0225			SL1	0,6375	0,3592		
SG2	0,8625	0,1725			SL2	0,0500	0,0282		
SG3	0,5375	0,1075			SL3	0,7375	0,4155		
SG4	0,0000	0,0000			SL4	0,3500	0,1972		
SG5	0,2250	0,0450			SEn			**4,3875**	**0,2498**
SG6	0,3625	0,0725			SEn1	0,0125	0,0028		
SG7	0,7375	0,1475			SEn2	1,0000	0,2279		
SG8	0,8750	0,1750			SEn3	0,5625	0,1282		
SG9	0,6250	0,1250			SEn4	0,0000	0,0000		
SG10	0,6625	0,1325			SEn5	0,5000	0,1140		
SE			**4,0750**	**0,2320**	SEn6	0,5625	0,1282		
SE1	0,6875	0,1687			SEn7	0,6625	0,1510		
SE2	0,3375	0,0828			SEn8	0,6250	0,1425		
SE3	0,6875	0,1687			SEn9	0,0000	0,0000		
SE4	0,6125	0,1503			SEn10	0,4625	0,1054		
SE5	1,0000	0,2454			**SM**			**0,1625**	**0,0093**
SE6	0,0125	0,0031			SM1	0,0500	0,3077		
SE7	0,7375	0,1810			SM2	0,1125	0,6923		
SP			**2,1625**	**0,1231**					
SP1	0,4625	0,2139							
SP2	0,1000	0,0462							
SP3	0,8625	0,3988							
SP4	0,7375	0,3410							

Table 5.11: Fuzzy Evaluation Matrix MF of all Indicators and Domains

Ind	Weight	MF First Level for Indicators					MF Second Level for Domains				
		B	D	Im	A	In					
SG							**[0,0813**	**0,1902**	**0,3045**	**0,2829**	**0,1411]**
SG1	0,0225	[0.35	0.40	0.20	0.05	0.00]					
SG2	0,1725	[0.05	0.15	0.25	0.35	0.20]					
SG3	0,1075	[0.10	0.20	0.45	0.20	0.05]					
SG4	0,0000	[0.40	0.45	0.10	0.05	0.00]					
SG5	0,0450	[0.25	0.45	0.20	0.08	0.02]					
SG6	0,0725	[0.15	0.35	0.35	0.12	0.03]					
SG7	0,1475	[0.05	0.15	0.30	0.35	0.15]					
SG8	0,1750	[0.03	0.12	0.25	0.35	0.25]					
SG9	0,1250	[0.08	0.18	0.35	0.28	0.11]					
SG10	0,1325	[0.07	0.17	0.32	0.30	0.14]					
SE							**[0,0590**	**0,1597**	**0,2988**	**0,3195**	**0,1630]**
SE1	0,1687	[0.05	0.15	0.30	0.35	0.15]					
SE2	0,0828	[0.15	0.35	0.35	0.12	0.03]					
SE3	0,1687	[0.05	0.15	0.30	0.35	0.15]					
SE4	0,1503	[0.08	0.18	0.35	0.28	0.11]					
SE5	0,2454	[0.03	0.10	0.25	0.35	0.27]					
SE6	0,0031	[0.40	0.45	0.10	0.05	0.00]					
SE7	0,1810	[0.05	0.15	0.30	0.35	0.15]					
SP							**[0,0699**	**0,1745**	**0,3075**	**0,3054**	**0,1425]**
SP1	0,2139	[0.10	0.20	0.45	0.20	0.05]					
SP2	0,0462	[0.25	0.45	0.20	0.08	0.02]					
SP3	0,3988	[0.05	0.15	0.25	0.35	0.20]					
SP4	0,3410	[0.05	0.15	0.30	0.35	0.15]					
SL							**[0,0904**	**0,2087**	**0,3222**	**0,2711**	**0,1078]**
SL1	0,3592	[0.08	0.18	0.35	0.28	0.11]					
SL2	0,0282	[0.40	0.45	0.10	0.05	0.00]					
SL3	0,4155	[0.05	0.15	0.30	0.35	0.15]					
SL4	0,1972	[0.15	0.35	0.35	0.12	0.03]					
SEn							**[0,0724**	**0,1654**	**0,3439**	**0,2808**	**0,1375]**
SEn1	0,0028	[0.40	0.45	0.10	0.05	0.00]					
SEn2	0,2279	[0.03	0.10	0.25	0.35	0.27]					
SEn3	0,1282	[0.08	0.18	0.35	0.28	0.11]					
SEn4	0,0000	[0.40	0.45	0.10	0.05	0.00]					
SEn5	0,1140	[0.10	0.20	0.45	0.20	0.05]					
SEn6	0,1282	[0.08	0.18	0.35	0.28	0.11]					
SEn7	0,1510	[0.07	0.17	0.32	0.30	0.14]					
SEn8	0,1425	[0.08	0.18	0.35	0.28	0.11]					
SEn9	0,0000	[0.40	0.45	0.10	0.05	0.00]					
SEn10	0,1054	[0.10	0.20	0.45	0.20	0.05]					
SM							**[0,3654**	**0,4154**	**0,1692**	**0,0500**	**0,0000]**
SM1	0,3077	[0.40	0.45	0.10	0.05	0.00]					
SM2	0,6923	[0.35	0.40	0.20	0.05	0.00]					

The study demonstrates how the domain and indicator weightings were determined and calculated. The values were computed by applying the weighting Equation 3 to each domain and indicator.

$$W_i = \frac{M_j}{\sum_{i=1}^{5} M_j}, 0 < W_i < 1, and \sum_{i=1}^{n} W_i = 1$$

Equation 3

Equation 3's demonstrational process highlights $\boldsymbol{W_i}$ as a representation of weightings for each domain or indicator, while $\boldsymbol{M_j}$ denotes the mean score of each domain or indicator, *i* ranges from 1 to 5 based on the 5-point grading scale, and $\sum \boldsymbol{M_j}$ Signifies the total value for all indicators in each domain. Similarly, the total weight for each domain can be derived by using the same approach. For example, the use of SG1 indicator value 0.1125 and total SG value 5.0000 to calculate a weighting of 0.02439 is shown below. The information presented in Table 5.10, particularly the weightings column, was calculated through the data value column using the equation above to obtain the weightings for each indicator.

WSG1

$$= \frac{0{,}1125}{0{,}1125 + 0{,}8625 + 0{,}5375 + 0{,}0000 + 0{,}2250 + 0{,}3625 + 0{,}7375 + 0{,}8750 + 0{,}6250 + 0{,}6625}$$

$$= \frac{0{,}1125}{5{,}0000} = 0{,}0225$$

Likewise, the weightings for the other indicators were all calculated using the same procedure. Also, the normalized weighting functions satisfy the condition in Equation 1, as verified by the sum of the normalized weightings across all ten indicators in Table 5.10 being equal to one. For example, the normalized weighting for all indicators is calculated as follows:

$$\sum_{i=1}^{10} W_i = 0{,}0225, +0{,}1725 + 0{,}1075 + 0{,}0000 + 0{,}0450 + 0{,}0725 + 0{,}1475 + 0{,}1750 + 0{,}1250$$

Equally, the summation of all the domains of the study is computed. The use of SG domain value 5,0000 and total domains value 17,5625, for example, to calculate the SG weighting value 0,2847, is illustrated below.

$$WSG = \frac{5{,}0000}{5{,}0000 + 4{,}0750 + 2{,}1625 + 1{,}7750 + 4{,}3875 + 0{,}1625} = \frac{5{,}0000}{17{,}5625} = 0{,}2847$$

Likewise, the weightings for the other domains were all calculated using the same procedure. Furthermore, to verify the domains, the sum of the normalized weightings across all six domains in Table 5.10 equals 1. The calculation for normalized domain weightings for all indicators is shown here:

$$\sum_{i=1}^{6} W_i = 0{,}2847 + 0{,}2320 + 0{,}1231 + 0{,}1011 + 0{,}2498 + 0{,}0093 = 100$$

5.4 Determining Membership Function for Each Indicator and Domains

The most common types of member functions are triangular, trapezoidal, generalized bell, and Gaussian. Nevertheless, the Gaussian membership function is used across various engineering and applied science disciplines to explain the behaviour and statistical distributions of many natural phenomena, as well as to represent measurement uncertainty (Revathi, Shirley & Sreethar, 2025). Trapezoidal membership functions, on the other hand, because of their flexibility and fast computation, which make them popular in fuzzy systems representing concepts with a central certainty, have been chosen in this study. This degree of membership is a value between 0 and 1, where 0 indicates that the element is not a member and 1 indicates that it is a full member.

The computation for the MF matrix of each indicator employed Equation 2 and the trapezoidal fuzzy five-point mapping scale, where 1 represents basic (B), 2 developing (D), 3 intermediate (Im), 4 advanced (A), and 5 Innovative (In), as shown in Table 5.9. Thus, the computed fuzzy matrices are plotted as the *MF first-level indicators* in Table 5.11. Importantly, these two can accurately calculate and plot the matrix using the mapped values, thereby avoiding the subjectivity of human interference with the data. This further ensured that the allocated matrix represents fairly weighted values, accounting for what could be unfairly achieved by simply using the indicator's mean and standard deviation, as required for a Gaussian distribution. See how each indicator matrix computation was carried out in Appendix G.

The MF matrix for each domain was computed using the fuzzy matrix given by Equation 4. The values for C1 to C5 are the level one MF of each indicator, as shown in Table 5.11. Given the fuzzy matrix $\mathbf{Y}_i$ and the indicator weightings $\mathbf{W}_i$ in Table 5.11, the fuzzy evaluation matrix $\mathbf{Z}_i$ can be calculated.

$$Z_i = W_i \otimes Y_i = \{w_1,\ w_2,\ w_3,\ .,\ w_n\} * \begin{bmatrix} C1_{ui1} & C2_{ui1} & C3_{ui1} & C4_{ui1} & C5_{ui1} \\ C1_{ui2} & C2_{ui2} & C3_{ui2} & C4_{ui2} & C5_{ui2} \\ C1_{ui3} & C2_{ui3} & C3_{ui3} & C4_{ui3} & C5_{ui3} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ C1_{uin} & C2_{uin} & C3_{uin} & C4_{uin} & C5_{uin} \end{bmatrix} = (z_{i1},\ z_{i2},\ \ldots,\ z_{in})$$

Equation 4

Where $\mathbf{Z_i}$ is the degree of membership function of the grade alternative for a given domain, and ⊗ is the fuzzy composite operator. For instance, as shown in Table 5.11, SG contains 10 indicators with the weighting WSG = (0.0225, 0.1725, 0.1075, 0.0000, 0.0450, 0.0725, 0.1475, 0.1750, 0.1250, 0.1325), reflecting the MF of the indicators in this domain from SG1 to SG10. Depicted in Figure 5.2 is the fuzzy evaluation matrix using Equation 4 to calculate the *MF second-level of domains* for SG presented in Table 5.11. This equation multiplies each MF matrix column by a set of weights and adds. Calculation example is shown below using the first column:

$$W_{SG} = 0.0225, 0.1725, 0.1075, 0.0000, 0.0450, 0.0725, 0.1475, 0.1750, 0.1250, 0.1325 \quad * \begin{bmatrix} 0.35 & 0.40 & 0.20 & 0.05 & 0.00 \\ 0.05 & 0.15 & 0.25 & 0.35 & 0.20 \\ 0.10 & 0.20 & 0.45 & 0.20 & 0.05 \\ 0.40 & 0.45 & 0.10 & 0.05 & 0.00 \\ 0.25 & 0.45 & 0.20 & 0.08 & 0.02 \\ 0.15 & 0.35 & 0.35 & 0.12 & 0.03 \\ 0.05 & 0.15 & 0.30 & 0.35 & 0.15 \\ 0.03 & 0.12 & 0.25 & 0.35 & 0.25 \\ 0.08 & 0.18 & 0.35 & 0.28 & 0.11 \\ 0.07 & 0.17 & 0.32 & 0.30 & 0.14 \end{bmatrix}$$

(0,35 * 0,0225) +(0,05 * 0,1725) +(0,10 * 0,1075) +(0,40 * 0,0000) +(0,25 * 0,0450) +(0,15 * 0,0725) +(0,05 * 0,1475) + (0,03 * 0,1750) +(0,08 * 0,1250) +(0,07 * 0,1325) = **0,0813**

(0.0760, 0.1789, 0.3139, 0.2903, 0.1408)

Figure 5.2: Fuzzy Evaluation Equation MF Second Level (Author)

Similarly, the fuzzy evaluation matrices for the other domains were calculated using the same procedures.

Equation 5 below represents the formula used to calculate the **Development Index**, where $\boldsymbol{w_j}$ is the given weights and μ_j is the fuzzy membership value from the matrix.

$$DI = \sum_{j=1}^{n} w_j \mu_j(x)$$

Equation 5

The degree of MF is estimated for each grade alternative for a domain. For example, the fuzzy evaluation matrix in Figure 5.3 shows a set of five MF for each of the six domains, along with their corresponding weights (0.0760, 0.1789, 0.3139, 0.2903, 01408). Additionally, Figure 5.3 illustrates how the fuzzy evaluation matrix is calculated as the product of the weights and the MF.

The calculations are carried out using a fuzzy evaluation matrix as the product of the weights and the MF, like Figure 5.2, where the weights represent the relative importance of each category using Equation 4 as follows:

$$W_{Overall} = 0.2847, 0.2320, 0.1231, 0.1011, 0.2498, 0.0093 \; * \begin{bmatrix} 0{,}0813 & 0{,}1902 & 0{,}3045 & 0{,}2829 & 0{,}1411 \\ 0{,}0590 & 0{,}1597 & 0{,}2988 & 0{,}3195 & 0{,}1630 \\ 0{,}0699 & 0{,}1745 & 0{,}3075 & 0{,}3054 & 0{,}1425 \\ 0{,}0904 & 0{,}2087 & 0{,}3222 & 0{,}2711 & 0{,}1078 \\ 0{,}0724 & 0{,}1654 & 0{,}3439 & 0{,}2808 & 0{,}1375 \\ 0{,}3654 & 0{,}4154 & 0{,}1692 & 0{,}0500 & 0{,}0000 \end{bmatrix}$$

$$= 0.0760, 0.1789, 0.3139, 0.2903, 0.1408$$

Figure 5.3: Fuzzy Evaluation Equation MF Third Level (Author)

MF values for the first column are multiplied vertically by the set of $W_{Overall}$ weightings as shown by Figure 5.3, which yields the first development index value as 0.0760; similarly, the second development index (0.1789) is calculated by multiplying the second MF values column by the weightings vertically. Lastly, the remaining columns are calculated using the same set of overall weightings to determine the third (0.3139), fourth (0.2903), and last value (0.1408) of the development index, respectively.

5.5 Computing the Overall Smartness Development Index

By combining the fuzzy evaluation matrices for each domain with the five-point Likert scale used in the study, the indices for the six domains could be computed. A mathematical formula for the overall smartness development level index is given in Equation 4, which is followed by a detailed explanation.

$$D_{index} = \sum_{i=1}^{5} (DI \; x \; R)$$

Equation 4

The letter **R** in Equation 4 represents a rating scale (1, 2, 3, 4, 5), like the Matjhabeng smart city matrix level used to assess the smartness process. Shown as **DI**, scores such as (0.0760, 0.1789, 0.3139, 0.2903, 0.1408) are in this system determined for a given domain using a fuzzy evaluation matrix. Crucially, $\mathbf{D_{index}}$ contributes to the final calculation of a score indicating that the municipality is overall intelligent (Nguyen & Nguyen, 2024). To calculate the six critical key domains' smartness scores, this equation was exploited. Hence, adopting Equation (5), the smartness development level index of the six domains of the Matjhabeng municipality could be computed as:

SG = [0.0813, 0.1902, 0.3045, 0.2829, 0.1411] * [1, 2, 3, 4, 5] = [0.0813 * 1 + 0.1902 * 2 + 0.3045 * 3 + 0.2829 * 4 + 0.1411 * 5] = 3,2125

SE = [0.0590, 0.1597, 0.2988, 0.3195, 0.1630] * [1, 2, 3, 4, 5] = [00590. * 1 + 0.1597 * 2 + 02988 * 3 +0.3195 * 4 + 0.1630 * 5] = 3,3679

SP = [0.0699, 0.1745, 0.3075, 0.3054, 01425] * [1, 2, 3, 4, 5] = [0.0699 * 1 + 0.1745 * 2 + 0.3075 * 3 + 0.3054 * 4 + 01425 * 5] = 3,2758

SL = [0.0904, 0.2087, 0.3222, 0.2711, 0.1078] * [1, 2, 3, 4, 5] = [0.0904 * 1 + 0.2087 * 2 + 0.3222 * 3 + 0.2711 * 4 + 0.1078 * 5] = 3,0974

SEn = [0.0724, 0.1654, 0.3439, 0.2808, 0.1375] * [1, 2, 3, 4, 5] = [0.0724 * 1 + 0.1654 * 2 + 0.3439 * 3 + 0.2808 * 4 + 0.1375 * 5] = 3,2457

SM = [0.3654, 0.4154, 0.1692, 0.0500, 0.0000] * [1, 2, 3, 4, 5] = [0.3654 * 1 + 0.4154 * 2 + 0.1692 * 3 + 0.0500 * 4 + 0.0000 * 5] = 1,9038

Table 5.12: Domain Level Results

Domain	Development Index	Status
Smart Governance (SG)	3,2125	Advanced Level
Smart Economy (SE)	3,3679	Advanced Level
Smart People (SP)	3,2758	Advanced Level
Smart Living (SL)	3,0974	Advanced Level
Smart Environment (SEn)	3,2457	Advanced Level
Smart Mobility (SM)	1,9038	Developing Level

In the same vein, the fuzzy set evaluation (FSE) values presented in Table 5.11 are considered significant. The MF values and weights of all six domains were combined to produce the overall MF for Matjhabeng's smartness. In short, the MF values given to the fuzzy method and the use of Equation 4 have assisted in predicting the overall smartness score for Matjhabeng. Research information was assessed and published using MATLAB® R2022b.

Smartness development index = [0.0760, 0.1789, 0.3139, 0.2903, 0.1408] * [1, 2, 3, 4, 5] = [0.0760 * 1 + 0.1789 * 2 + 0.3139 * 3 +0.2903, * 4 + 0.1408 * 5] = 3,2409

Based on the above computation, the overall smartness development index was computed through the product of DI and a five-point Likert scale. First, the first DI value is multiplied by scale 1; then the second DI value is multiplied by scale 2, and the process continues until all five sets of values have been calculated. In the end, after the products are calculated, a sum is computed to determine the overall results of the Matjhabeng's smartness development level index.

To evaluate the overall smartness index using a five-point Likert scale, we need to define the scale using Table 5.13. It is equally important to note that this table corresponds to Table 4.2 in Chapter 4, which provides details of each level, explaining, for example, what is meant by a municipality being at the following levels: basic, developing, intermediate, advanced, and innovative. In summary, the table below shows different ranges and their equivalent ranking-scale interpretations. This table's first row highlights that the overall smartness index ranges from 0 to 1, with a ranking scale interpretation at the basic level, followed by a smartness index ranging from 1 to 2, with a ranking scale interpretation at the developing level. The next row shows the smartness index, which ranges from 2 to 3 and is ranked at an intermediate level. Finally, the overall smartness index ranking places anything above 4-5 in the highest tier, the innovative level, and anything above 3-4 in the advanced level.

Table 5.13: Overall Smartness Index Ranking

Range	Ranking scale interpretation
(0-1)	Basic level
(>1-2)	Developing level
(>2-3)	Intermediate level
(>3-4)	Advanced level
(>4-5)	Innovative level

5.6 Findings

The analysis revealed the smartness status for all six domains of Matjhabeng Municipality, determined using a five-point Likert scale. Also, the municipality's overall smartness level index after the FSE analysis was 3,2409, which is approximately at the centre of the fuzzy space. Based on the municipality's smart city five-point level matrix adopted for this study, the municipality's level of smartness is determined using five ranking levels. Likewise, the smart development level indices of all six domains of the municipality are at an **advanced level**. The implications of these levels of indices for each domain are further elaborated as follows:

Smart Governance

The governance domain, as the backbone driving the municipality's administration, ranked at 3,2125, placing it at an advanced level of smartness; however, the best news was that it ranked above the average of other domains. For this reason, it can be inferred that the municipality's initiatives, such as collaboration, e-governance, decision-making, and integration, exceed acceptable levels for classification as a smarter municipality in terms of governance. Nevertheless, this study is not intended to suggest or address how a municipality can improve its smartness rank. Admittedly, as the municipality grows, to monitor and protect citizens, technological initiatives should be put in place to ensure effective use of Big Data for informed decision-making. Dhenge and Nimbarte (2024) asserted that, for smart governance to be achieved, a transparent governance system is necessary to enhance citizens' safety and well-being.

Smart Economy

Although sitting slightly above smart people, this was the first-most developed domain among the six domains used to determine the smartness level index, at 3,3679, and ranked at the **advanced level**. The domain consists of “career paths for youth,” “opportunities based on collaboration,” “platforms for presenting fundable ideas (imbizos),” and “centres supporting research and development efforts,” amongst other indicators. This study found that the domain should measure the effectiveness of the indicators mentioned earlier in creating job opportunities, promoting high-quality living, and sustaining economic growth. The smartness level index for this domain indicates that the municipality is developing rapidly. The domain's statistical data demonstrated tremendous progress while also suggesting areas for further investment and collaboration to improve effectiveness.

Smart People

This domain is currently at a smartness level index of 3,2758, just below smart economy, making it the second highest among the other domains; however, it also falls within the **advanced level** ranking. As noted, the study does not aim to suggest specific activities to improve smartness; lessons learned from this domain may nevertheless contribute to increasing smartness. They should be considered seriously by policymakers and developers. Anderson and Jung (2023) mentioned that people make up the city. Therefore, all the other domains should be implemented to ensure the safety of the people, their inclusiveness, and their resourcefulness in the municipality. Hence, an accurate measure of the municipality's smartness lies in the people domain. Therefore, excellent schools and institutions of higher learning ought to be built, empowered, and supported to foster creativity and soft skills among the municipality's citizens. The support to these institutions should include, but not be limited to, human resources and infrastructure to strengthen their ability to enhance people’s communication skills, technology usage, and their competence in utilising data (Giffinger *et al*., 2007).

Smart Living

This domain, like others, has been assessed to gauge the municipality's overall smartness (Antwi-Afari *et al*., 2021). The well-being of citizens was the key to measuring this domain in the municipality. The domain ranked second-to-last at 3,0974; it is above the 3.0172 acceptable threshold and therefore is ranked at the **advanced level** of smartness. Policymakers and urban planners could enhance this domain by improving the identified indicators and their derivatives through the enrichment of the health system and social services in the city, encouraging more healthy agricultural yields for the municipality and promoting a city of inclusion, love, cultural integration, environmental and material well-being, and a sense of shared value among the citizens (Giffinger *et al*., 2007).

Smart Environment

The environment domain ranked third among the domains used to classify the municipality's smartness status, with a ranking of 3,2457, placing it in the advanced category. Though the city was previously known as the Circle City and City Within a Garden, much of the green vegetation and many parks and trees have now been levelled to make way for the growing population, mobility, markets, and housing in the municipality (Maphalala, 2022). It could be attributed to why data sources ranked this domain relatively developed for a previous environmental hub municipality. Also, for this domain, it is not the place of this study to recommend improvements. Still, high-ranking municipal officials may utilise the findings of this study to plan masterworks with the environment in mind, integrating and maintaining infrastructure and ecological systems sustainably (Antwi-Afari *et al*., 2021). Other indicators in this domain which ranked very low, such as "Satisfaction level of citizens with provision and installation of street lighting," "Level of investment to support plans to explore the use of waste-to-energy as a viable solution," and "Level of functional water distribution networks," should receive significant attention and support as a measure aiming to enhance the safety, greenness, and livelihood of the municipality.

Smart Mobility

This domain was the last to be underdeveloped in the municipality, ranked at the developing level in the study's ranking matrix. Although there is limited noticeable development in the provincial road networks intersecting within the municipality, little is known about the status of municipal roads and the repair of old roads to improve the general accessibility of its business districts. Notwithstanding, since this domain deals with indicators such as "integrated transport plan" and "regulatory compliance for public transport systems," which available data ranked poorly, it is entirely in the hands of policymakers to consider improving these indicators through several initiatives at their disposal, like incorporating emerging technologies such as computer vision and light detection and ranging to improve overall travelling efficiency and reduce accidents on roads. Equally important, the municipality's accessibility for persons with disabilities is a fascinating indicator of smartness and should be drastically improved.

5.7 The Generic and Applicability of the SAF Framework

Despite minor challenges in size, geographic location, technology stage, or financial status, the SAF can be implemented in a wide range of municipalities without requiring significant modifications. Similarly, internationally acclaimed domains such as smart governance, economy, people, living, environment, social engagement, and smart mobility, which are found in most frameworks, are also present in SAF. These critical domains, as acknowledged in the literature, constitute a significant part of the framework aimed at enhancing the assessment of the preparedness of a prioritised local municipality. Standardised indicators that combine relevant evaluation criteria with a certain level of resources are also incorporated. While the frameworks have contributed to the study of smart cities in relation to smartness readiness, none of the studies have focused on a specific number of indicators identified per SAF domain see below Table 4.3 in Chapter 4, and waste management and reporting mobile app to address the smart environment component of the framework; thus, SAF is unique in the sense that it addresses the mentioned aspects. As such, the framework's applicability underscores the value of SAF as a tool not only for assessing Matjhabeng's readiness for smart city development, but also for other municipalities facing challenges like those of the municipality under study. SAF is the answer to municipalities in South Africa's need to adopt approved approaches to assess their smart city readiness as smart city initiatives gain momentum. Consequently, by making it broadly applicable and valuable across diverse municipal contexts, municipalities can adapt the framework as both a benchmarking tool for assessing their performance and a readiness guide for preparing specific areas for improvement.

5.8 Summary

Following on from the SAF analysis, this section analysed and discussed the measurement across all elements of the framework. The nature of the chapter meant it strove to understand, evaluate, and analyse smartness performance using the municipality's IDP and StatsSA as secondary data sources, and to examine their respective perspectives, though a technological focus still emerged. Some scientific approaches have been adopted to measure the municipality's smartness. The ranking of the six domains of the framework took centre stage, as did the calculation of the municipality's overall smartness level using fuzzy synthetic evaluation and multi-criteria decision-making methods.

Chapter 6 focuses on the detailed development of smart waste management and reporting.

CHAPTER SIX – CASE STUDY OF SMART WASTE MANAGEMENT AND REPORTING

6.1 Introduction

As discussed earlier in this thesis, waste and illegal dumping, and their collection, are ongoing challenges that have befallen South African municipalities, and Matjhabeng Local Municipality is not immune to this. Some residents have normalised illegal dumping due to the municipality's negligence and a lack of knowledge about the waste pickup schedule.

These challenges have led this study to propose developing a technology and IoT solution to assist the municipality in managing waste effectively, enabling residents to receive real-time updates, be notified of schedule changes, and report issues such as illegal dumping and missed collections. Developing a mobile application will enhance waste management strategies and methods in Matjhabeng by allowing an administrator to monitor reported issues and view community reviews.

Most notably, this chapter aims to satisfy objective number four of the overall research: To use a case study of a mobile application system to evaluate the framework developed. The creation of this intervention in this chapter addresses one of the research framework's essential indicators as part of the assessment process, namely, solid waste. This indicator is one of the criteria used to evaluate the smart environment domain, one of the domains that comprises the study framework.

This mobile application seeks to improve waste transportation and collection, and provide communication between the two parties using mobile app technology. In polluted environments, automated systems and humans must collaborate to address air pollution and illegal dumping. Furthermore, this chapter demonstrates the analyses, design, implementation, and evaluation of the integrated waste mobile application and describes it in detail.

6.2 System Design Development and Documentation

Implementing a mobile application for waste management involves several stages, including information gathering, user-friendly interface design, and application testing. This application includes straightforward processes such as requesting waste collection vehicles, reporting problems, providing real-time updates, and providing feedback. The mobile application has been designed and developed, and has undergone reliability and security testing to ensure it is reliable and can handle multiple requests. Testing included usability testing during implementation, with the application evaluated through controlled experiments and real-time scenarios.

The mobile application runs on Android and requires an internet connection to allow users to log in, as the database verifies user accounts online. Users can access menu options after a successful login, and the mobile application is user-friendly and accessible to users of all ages.

The app is designed with scalability in mind to accommodate future growth in user base and service demand. This optimises app performance to ensure smooth operation even during peak usage periods. This app offers the user the following options: (1) to request waste collection services by enabling the user to type and quantify the waste to be collected; (2) to schedule collection pickups for specific dates and times; and lastly, (3) to enable users to track the status of their collection request in real time.

6.3 System Database Design and Implementation

This research uses Backendless as the database to implement the design, and the database data is uploaded to the server in real-time.

Backendless provides a free, robust platform and services for backend development. It serves as the cloud foundation platform, and the saved data is available in real time. This database integrates tables effortlessly and offers several built-in features, including user administration, push notifications, geolocation, and file storage, enabling seamless data analysis. Furthermore, Backendless provides the server-side functionality needed to upload files and perform record-related operations, such as creating, reading, updating, and deleting. Notably, it is an open-source database that is easy to utilise with Android, iOS, JavaScript, and Flutter.net apps. It also provides a visual application development platform, allowing you to easily build user interfaces and connect them to the server.

6.4 System Architecture and Middleware Implementation

The mobile application structure breakdown is presented in Figure 6.1 below:

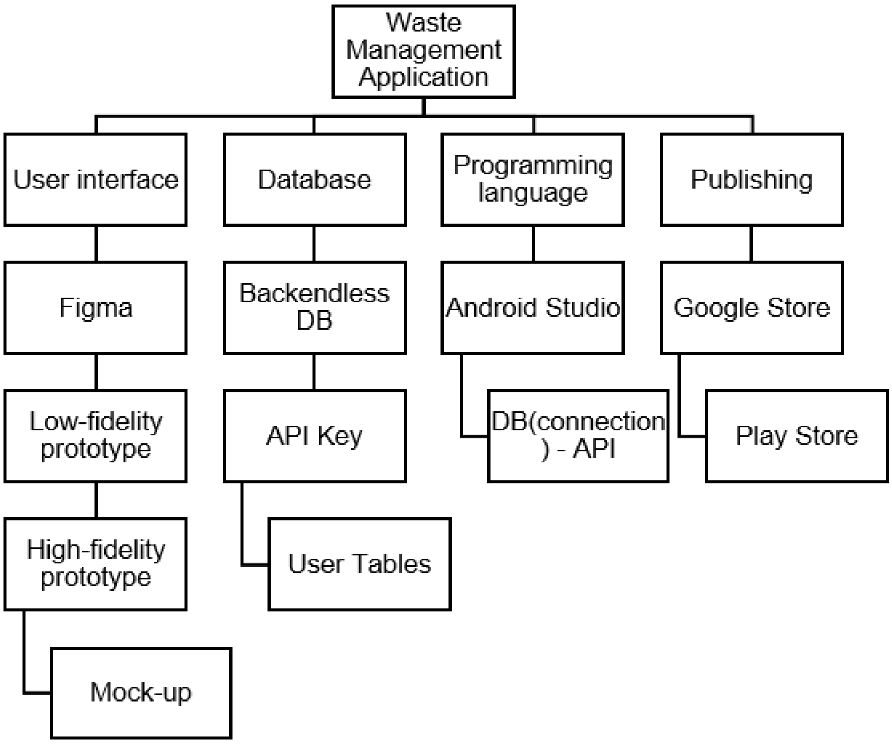

Figure 6.1: Mobile Application Structure Breakdown (Author)

A conceptualised system integration and design architecture is illustrated in Figure 6.2, showing how the application, middleware, and different hardware components interact.

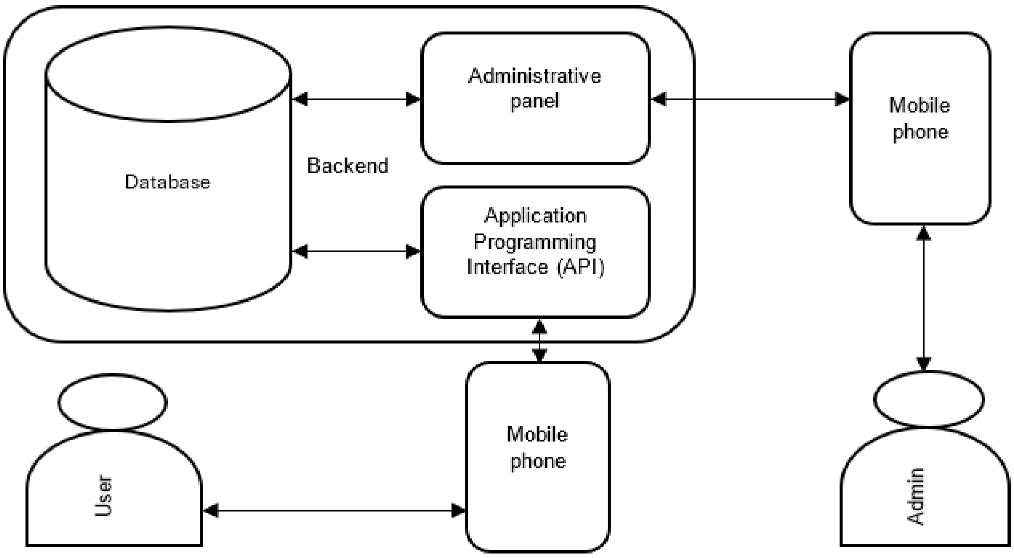

Figure 6.2: System Components Integration and Interaction (Author)

6.5 System Graphical User Interface

Graphical user interfaces (GUIs) facilitate communication between the frontend and backend components of the expert system module with the mobile applications. Two types of GUIs are available for this system's access: frontend and backend. The frontend GUIs, illustrated in

Figure 6.2, are designed to be intuitive and user-friendly. They include options for unregistered users to create profiles and log into the system. Meanwhile, Figure 6.3 shows the screen that appears upon successfully installing the mobile application on an Android smartphone.

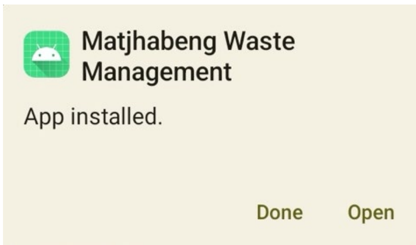

Figure 6.3: Mobile Application Installation (Author)

After the mobile app is successfully installed, the user is presented with the above confirmation dialog, prompting them to click ‘Done’ or ‘Open’ to launch the application. Once an Android APK of a mobile application is installed on a smartphone, it shows the symbol shown in Figure 6.4.

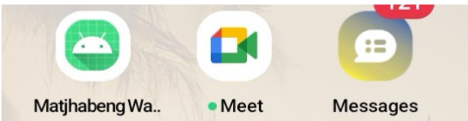

Figure 6.4: Mobile Application Icon (Author)

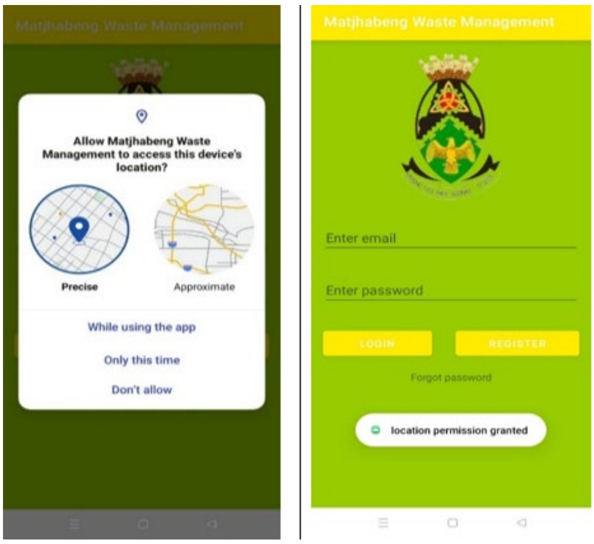

Figure 6.5: Using Google Maps Permission (Author)

When the mobile app initially launches, it will prompt the user to grant access permission, as shown on the left-hand side of Figure 6.5. To allow Google Maps to be used on the mobile device, the user must still check "While using the app." Once the user's mobile application grants permission to access location, a confirmation pop-up appears, as shown on the right-hand side of Figure 6.5. To ensure that only approved mobile app expert agents have access to the system, the application displays this Login Screen for authentication (Figure 6.5, right). Existing users can log in with their existing credentials, such as an email address and an encrypted password, as shown above; however, new users must first register. After successfully logging into the system, the program's Home Page will appear. Figure 6.6 depicts this interface’s four functions: Report Issue, Collection Schedule, Report Status, and Ratings and Feedback.

Figure 6.6: Home Page (Author)

As previously stated in the text, unregistered users are barred from accessing the system unless they register or build profiles that provide trustworthy credentials for logging in, as shown in Figure 6.7.

Figure 6.7: Registration Page (Author)

Figure 6.7 above is an example of a data-capture interface that includes fields for the data needed to construct a user profile. Before being granted access to the system, the user must complete the registration form and provide personal information, including their surname, mobile phone number, identification number, email address, account password, and account password confirmation. Once the user has entered the relevant data, the system stores the profile in the cloud-based database by pressing the 'Register' button. The interface accepts registrations from both administrators and regular municipal citizens. When this button is pressed, the system validates the data provided by ensuring that all fields are completed. Any incomplete fields or data that do not meet a field's validation criteria are flagged as errors, and the system indicates what needs to be corrected. Furthermore, password checks are crucial validations that occur here; a middleware service compares a specified data parameter, such as the first password, against the second password. Before storing a profile in the database, the system warns the user if one of the password values is dissimilar or empty.

6.6 Registration Interface Programming

The Registration interface code module is shown in Appendix E as an excerpt, which is considered a critical component of this interface. A key function of this code module is to allow users to be registered effectively in the application according to the established criteria, ensuring that only data that meets the application's requirements is stored in the database.

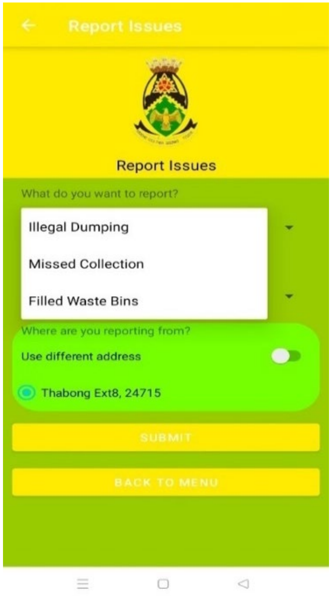

Figure 6.8: Report Issue (Author)

When creating a new report in the mobile application, customers can choose from three options: Illegal Dumping, Missed Collection, or Filled Waste Bins. This user-friendly interface captures data required to underpin and enhance the numerous system processes presented in Figure 6.8 above. In addition, the interface displays the user's current residential address and allows them to enter and use an alternate residential address in the report. After the user selects the reporting item, the system uses the signed-in user's address to create a single record, which is then sent to the database for storage when the ‘Submit’ button is pressed. All collected data is saved to the database, which generates an event instructing a middleware service to start the data-saving procedure.

Figure 6.9: Waste Collection Schedule (Author)

Figure 6.9 interfaces offer a continuously updated, preloaded waste-collection schedule for several suburbs in Matjhabeng Municipality. The user may select a suburb and view its collection schedule on weekdays by clicking the menu option. The frontend interface's criticality is entirely dependent on the administrator’s competence and efficiency in ensuring that community members receive consistent, up-to-date collection schedules for convenience. Thus, this scheduling interface allows community members to properly arrange their solid waste collection, avoiding the need to transfer rubbish to the street without knowing the pickup schedule. Having this information in the user’s hand promotes an informed, tension-free society that takes responsibility for preparing garbage for collection, thereby contributing to a safe, clean, and healthy environment. Thus, waste is kept in the yard, away from the risk of being spilled by, for example, street dogs, until the scheduled collection time for the specific suburb.

Figure 6.10: Status Report Page (Author)

The Figure 6.10 interface presents a list of all waste reports filed with the municipality, as retrieved from the online database repository by the mobile application. The status report includes information on the community member, such as their name, surname, residential address, type of waste, and reason for the delay. Equally important is the municipality's (administrator's) timely response to the reported issue, as represented on this interface. The state of the relevant report varies based on three options: 'no progress', 'in progress', and 'completed'. 'No progress' means that the complaint has not been addressed; 'in progress' means that the matter has received attention of the department; and 'completed' means that the complaint has been considered and resolved, such as the truck will be dispatched to the area or suburb of concern within a week of the complaint date.

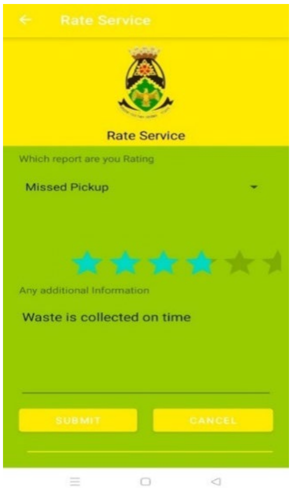

Figure 6.11: Rating & Feedback (Author)

Once the operation is completed, the user may leave comments and rate the municipal solid waste collection department, depicted in Figure 6.11. The comments might include complaints about missing collections, unlawful disposal, and overflowing bins. Once the municipality has completed waste collection in the neighbourhood, detailed feedback and an evaluation of municipal services based on user experience can be shared through this functionality. This feature was not only designed to highlight how users can actively engage with the system, but also to report service quality and contribute to improving municipal waste management.

6.7 Administrator Site Prototype (Backend GUIs)

The Home interface on the admin side of the application features three pages: Set Collection Schedule, Reported Issues, and Ratings and Feedback. The login page for both users and admins has the same interface. The administrator logs in and registers their account using an @municipality.com extension to be recognised as an administrator member of staff. One administrator is responsible for uploading the weekly schedule, reviewing all reported complaints, and reviewing all user feedback. Every suburb has its own waste pickup schedule, and the administrator will have to assign workers to the specific area reported.

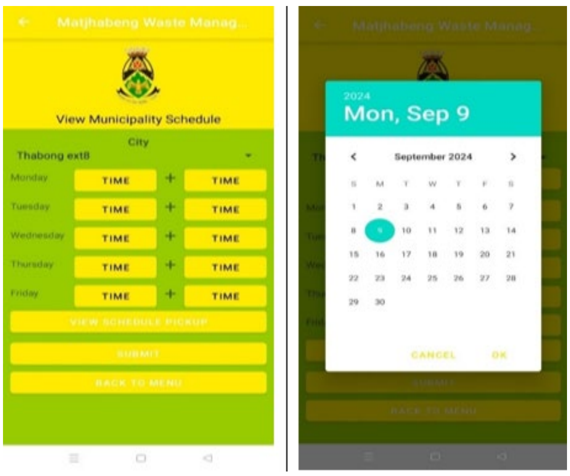

Figure 6.12: Set Waste Collection Schedule (Author)

Figure 6.12 above depicts the user-friendly backend interface of the Set Collection Schedule page, which allows administrators to create and amend suburbs' weekly collection schedules. The drop-down menu lists the many suburbs in Matjhabeng Municipality from which they can choose to amend their weekly timetable. Furthermore, the administrator may define time slots for each day of the week by clicking the time function, selecting the working hours after completing the weekly plan, and clicking the 'Submit' button to change the schedule. Finally, click the 'View Schedule Pickup' option to see the most recently updated and current schedules. Once the schedule is finalized, click the 'Back to Main Menu' button to return to the Home page. From now on, customers will be able to view the revised weekly schedule in the mobile application.

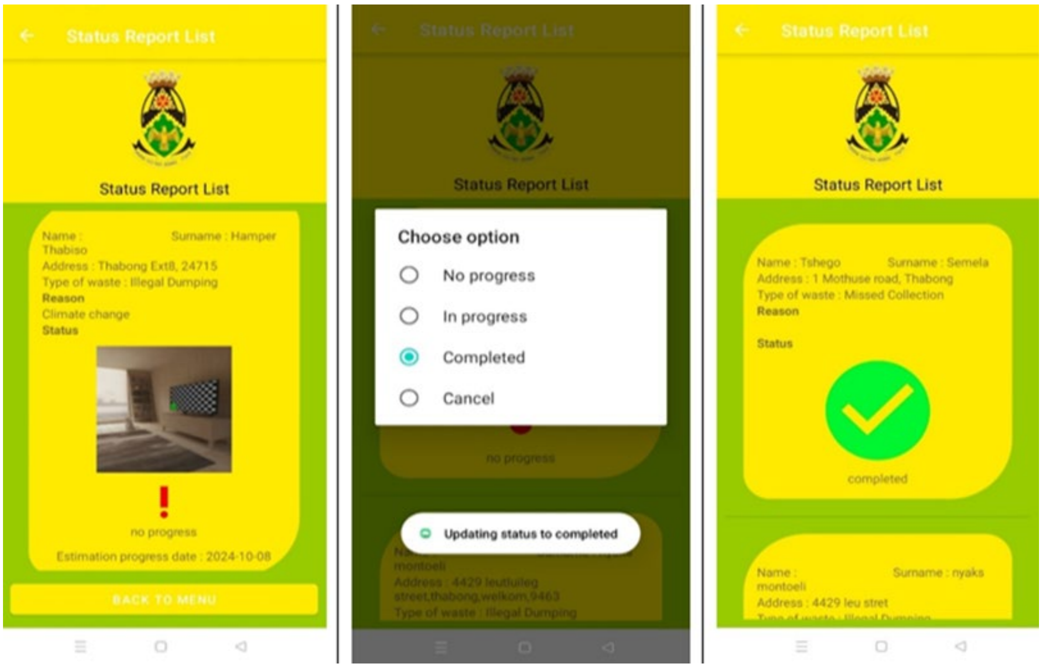

Figure 6.13: Status Report List (Author)

As stated previously in the text, when a user reports uncollected garbage using the mobile application, the report is saved in the database under the status report list, as illustrated in Figure 6.13. This page lists all the concerns reported by community members, which may be seen by scrolling up or down. The administrator has the authority and obligation to update this information in real-time to satisfy the request submitted by the community member. To change the status of a reported issue, press and hold the specific report; a menu appears with several status options: 'No Progress', 'In Progress', 'Complete', and 'Cancel'. The administrator may then click the status option appropriate to that specific report. Once the report has been processed and rubbish collected, the administrator can successfully change the status to 'Complete'. Furthermore, the application allows the administrator to view the specific location of the reported issue by clicking the report, which opens Google Maps where the exact location can be selected. Using this tool, the municipality can make it easier to identify remote unlawful dumping sites by allowing community members to take a photo of the area and report it to the municipality immediately.

6.8 Status Report Programming

An excerpt from the Status Report List code module, which serves as the backbone of the interface in many respects, is depicted in Appendix F. The key functionality of this code module is to integrate and neatly display an array of reports, update their status, and enable Google Maps to determine the reporter's location directly from where the report was submitted.

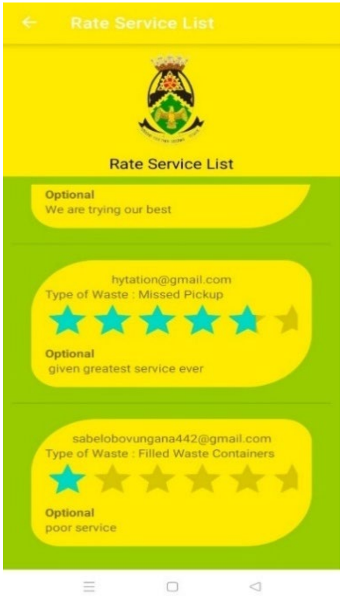

Figure 6.14: List of Comments and Feedback (Author)

The Figure 6.14 interface allows the administration to review residents' comments on the municipality's services. To access all the ratings and feedback from community members, the administrator navigates to the Ratings and Feedback page. This interface allows the administrator to navigate up and down and examine all the ratings and criticisms submitted by community members. Thus, each user review may be read as their perspective on their experience, highlighting strengths or areas for development, and awarding a rating that can also reflect their degree of satisfaction. Similarly, user feedback provides valuable insights into overall satisfaction in terms of professionalism, punctuality, and the quality of service offered by the municipality from the user's perspective. Furthermore, users' experiences are objectively recorded through ratings. As a result, the municipality may gather valuable insights, address concerns, and enhance service delivery by soliciting complete feedback. Similarly, this feedback assists the municipality in assessing service quality, identifying areas for improvement, and maintaining responsibility. Significantly, the system was presented to municipal managers, who seemed eager to adopt it

6.9 Summary

This chapter provided the reader with an overview of the various components of the mobile application system, an overview of the interaction diagram, and insights into the development of the mobile application intervention.

The various phases and internal procedures for logging in users and administrators to the system via the three-tier architecture were discussed. How the system takes login credentials through the user interface and then uses the business tier to validate the user was also outlined. Finally, the mobile application GUIs, features, and functions that permit communication between the expert system module frontend and backend components and the mobile apps were discussed. Significantly, considerable focus was placed on the two types of GUIs used to traverse this system: frontend GUIs and backend GUIs. This chapter revealed the value of these GUIs and the overall importance of the mobile application for waste management and reporting in the municipality.

The next chapter presents ideas and conclusions based on the study’s overall findings.

CHAPTER SEVEN – EVALUATION, DISCUSSION, AND CONCLUSION

7.1 Introduction

A primary objective of this study was to develop and evaluate a framework to assess the level of smartness of the Matjhabeng Local Municipality. The purpose of this chapter is to discuss the contributions made by each chapter towards the study objectives. In this chapter, conclusions and recommendations will be derived from the literature review, international smart city best practices, South African smart city frameworks, and key stakeholders' views on municipalities' levels of smartness. In this discussion, we will discuss how the research findings operationalised the research objectives. Moreover, a mobile application focused on waste management and reporting was deployed for testing and exploration purposes. The conclusion will include suggestions for future research.

7.2 Evaluation of Thesis Objectives

This research aimed to develop an integrative SAF and a mobile application for the management and reporting of waste in Matjhabeng. To achieve this broad aim, the study set out to achieve specific objectives. The extent to which these objectives were met is outlined below.

7.2.1 Research objective one: To carry out a systematic review of IoT deployment within smart city implementations globally.

This objective was achieved through a thorough literature review of global smart cities, which informed the creation of a dedicated framework for this thesis. The review included integrated viewpoints from distinct areas and disciplines, followed by a thorough analysis and understanding of existing theoretical and empirical research on smart city initiatives. Furthermore, this objective examined a wide range of smart city concepts, including urban planning techniques, technological intervention, sustainability practices, and governance frameworks. Similarly, to better understand the adaptability of smart cities, the review developed a strong understanding by combining data from various research studies and their influence on urban living.

The literature review was included as a chapter in the thesis to provide a sound theoretical and empirical context for the investigation. This methodology enhanced the study’s grasp of international trends and best practices in smart city development, ensuring the thesis's quality and thoroughness. Essentially, the thesis suggestions have laid the groundwork for future research to address the knowledge gaps and rising difficulties identified by this assessment. Admittedly, the chapter made a substantial contribution to the discourse on smart urbanisation by linking scholarly findings with practical ramifications.

Reviewing the existing literature provided a critical analytical basis by referring specifically to the Giffinger framework. Key domains such as Smart Economy, Smart People, Smart Governance, Smart Mobility, Smart Environment, and Smart Living Conditions are examined through a structured lens, with the Giffinger framework, well-known for its comprehensive approach to smart city evaluation, serving as the basis. Accordingly, and more importantly, to ensure that the framework guided the construction of a strong baseline, the study identified and critically analysed its strengths, weaknesses, and applicability across various urban contexts.

The study adopted, altered, and refined its components based on insights from the Giffinger framework to align with the thesis's unique aims. Based on the current issues and opportunities highlighted in the literature, the study included new domains and indicators deemed significant. Furthermore, emergent themes in smart city concept development, such as digital inclusion, data governance, and municipal planning, were addressed through an iterative customising process to guarantee that the framework maintained the theoretical rigor of Giffinger's original framework. As a result of the modifications, a personalised framework for reviewing and leading smart city efforts was created, making the tool more comprehensive and customisable.

Chapter 4 of the thesis provides an in-depth explanation of the resulting framework and its key approach. This chapter discussed the theoretical and empirical contributions of the modified framework, as well as the precise reasons for selecting, analysing, and adapting the Giffinger framework. Furthermore, Chapter 4 established a clear relationship between the literature review and the study outcomes. Thus, presenting the framework as a fundamental component emphasises the rigorous analytical process that underlies the argument.

7.2.2 Research objective two: To review and assess the relevance and applicability of the smart city concepts, models, and frameworks in use within three selected South African municipalities.

Various studies have examined the implementation of smart city frameworks. Das (2015) noted that there is an argument for change in the perspectives on the development of cities. In addition, he further stated that many countries in the West and some developing countries are increasingly making concerted attempts to transform their cities into smart cities. Hence, the author presented how a city can be transformed into a smart city through exploiting Bloemfontein in South Africa as a case study to evaluate the performance of essential attributes under key sectors, such as economy, mobility, and governance, to observe the opportunities and challenges the city offers to transform it into a smart city (Das, 2015), and concluded his study by suggesting that there are encouraging indications in three sectors. The favourable characteristics of governance scenarios presented clear prospects; nonetheless, there were hurdles to overcome in the economy and mobility. The causal feedback maps revealed (1) reinforcement of the interrelationship between entrepreneurship, innovative spirit, productivity, economic image, and international embeddedness will foster a smart economy; (2) efficient public transportation and advancement of ICT systems will strengthen local accessibility and ensure an innovative, sustainable, and safe transportation system that will result in smart mobility; and (3) effective participation.

Ncamphalala and Vyas-Doorgapersad (2022) argued that public administration and service delivery are inextricably linked to ICT and called for digital, smart service delivery in South African municipalities. They contended that ICT projects aimed at transforming municipalities into smart cities provide seamless services through smart governance. The City of Ekurhuleni, better known as CoE, served as a case study, with the conclusion supporting the introduction of the e-service delivery model. The objective behind this strategy was to create a networked society by interlinking service delivery systems and providing a one-stop service centre in both rural and urban environments. In another study on the same municipality, Mokoena and Sebola (2022) suggested that, as cities get smarter, their research will show how evidence-based planning may help local governments develop scientific decision-making procedures and concluded that the Strategic Spatial Urban Development Decision Framework (SSUDDF) enabled them to streamline significant criteria and processes specific to strategic urban development in the town of Benoni, located in the City of Ekurhuleni, by utilising critical spatial policy and the municipality’s strategic objectives.

Arnardu and Francke (2021) discussed how Cape Town, as a smart city, might contribute to Africa's socioeconomic growth and boost the Smart Africa program. They also said that Africa has kept pace with technological advancements, notably in telecommunications; nevertheless, adopting 5G requires more than simply providing connectivity, as it offers immense opportunities for smart cities. Thus, they concluded that Cape Town, as a smart city, may contribute to Africa's socioeconomic growth by implementing the Smart Africa Manifesto principles. Their advice assisted ICT plans, policies, and municipal authorities in their transformation to smart cities, notably in Africa.

7.2.3 Research objective three: To develop an assessment framework for smartness in South Africa's municipalities.

The development of such a tool involved an adaptable, comprehensive component, called SAF, tailored to the Matjhabeng Local Municipality to quantify smartness status in South Africa's municipalities. This complex approach required the development of a framework to assess the smartness performance needed for this municipality, including the provision of assessment results and recommendations to adopt the framework. This framework ensures alignment with IDP priorities, such as inclusive economic growth, sustainable development, and social equity. It is designed to assess the level of smartness of municipalities and progress in integrating smart city principles.

The framework is designed around key domains of smart city development, including governance, mobility, people, environmental sustainability, economic growth, and quality of life (living). The measurable indicators tailored to South Africa's local-municipality realities, such as the provision of basic services, integration of renewable energy solutions, and promotion of equitable access to digital tools, among others, are included in each dimension. As an illustration, the following were identified as significant contributing factors: the governance dimension ought to emphasise transparency, participatory decision-making, and the use of digital platforms. In addition, critical indicators such as waste management, renewable energy adoption, and climate change resilience were identified as necessary within the environmental domains. Specific indicators contributing to framework validation are discussed below in Table 4.3 of Chapter 4. Overall, integrating the identified indicators from various municipal IDPs enabled the framework to identify strengths, gaps, and opportunities within municipal strategies. To align its goals with on-the-ground needs and capacities, the framework incorporated stakeholder input from municipal officials, communities, and technology providers to ensure relevance and practicality.

Critical stakeholders, including municipalities, the commercial sector, academics, and the public, were not overlooked; this participatory engagement method was used to ensure the framework's effectiveness. As a result of this collaborative effort, the framework reflects and ensures that the many demands and goals of smart city initiatives are met. Furthermore, by incorporating municipal officials and other stakeholders in the creation and implementation of evaluation instruments, this strategy facilitated capacity building. As a result, the framework fostered a sense of ownership and commitment to accomplishing the defined municipality goals through stakeholder buy-in.

To summarise, this framework provided proof of a benchmarking tool by allowing for the measurement of performance and smartness status against specified indicators. In essence, its adaptive and expandable architecture enables the municipality to modify its use based on available resources, stages of growth, and, most significantly, size. Furthermore, the framework enabled evaluation using data sources such as StatsSA, yielding actionable insights that informed its practical assessment. In simple terms, SAF ultimately aims to empower South Africa's municipalities by providing a smartness status through scientific assessment, from which municipalities can then self-improve or correct their processes to fulfil their mandate of providing a good quality of life for all citizens.

7.2.4 Research objective four: To use the case study of a mobile application system to evaluate the framework.

This objective was achieved through the meeting the researcher had with the stakeholders of the Community Services Directorate. This directorate provides services under the Smart Environment critical component of the framework domain. In this context, this domain, amongst others, includes sub-domains such as solid waste, where the waste management and reporting mobile app was conceptualised. The study chose this domain as a key means to demonstrate how the exploitation of a mobile app can meaningfully contribute to the development and enhancement of the smartness of the municipality's service delivery to citizens. Above all, during the meeting, the presentation was conducted, showcasing the mobile application to municipal stakeholders. This presentation accompanied the demonstration of the application, during which two stakeholders were asked to install it on their mobile phones. Thereafter, stakeholders were requested to provide the app with the required details to register them to gain access to the application. One registered as a resident in the community, while the other was requested to register as an administrator of the system.

Furthermore, as part of the demonstration, the application database was opened to allow the stakeholders to view it as evidence in real time while the information is securely stored in the database from the mobile application. Interestingly, for demonstration purposes, the stakeholders logged in to the application and, without any assistance, navigated it using the user-friendly interface. Among other things, a resident user could report uncollected waste through the application, view the status report for reported waste complaints, and rate the municipality's service. Similarly, the administrator user managed to access the application's backend, where they used the interface to set the collection schedule and the status report interface, which allowed them to respond to user complaints. At the end of the presentation, this is what the overall stakeholders had to say about the application:

> *Thank you so much. Guys, I am impressed, especially that this came from our very own university here and our community residents. It shows we are not sending our children to school. They can go to varsity as well and come up with good ideas such as this one. So, I am happy that you are showing us something like this; we need this. Our community is unsure when they should expect the waste collection. This will resolve the communication problem the municipality is currently experiencing* (Stakeholder 4).

> *So, it will be easy for me to hold some officials accountable for reporting this* (Stakeholder 5).

> *So, we are buying in, and the idea is beautiful and good, which is what we have been waiting for. This means you should communicate with the department director. I think that is it, thank you very much for coming to give this presentation, and we welcome it. I think we will all see you soon* (Stakeholder 6).

7.3 Discussions

The framework is neither intended to serve as a comprehensive master plan nor to address all challenges faced by the Matjhabeng Municipality, nor to transform it into a smart city from a non-smart city. However, the municipality's current level of smartness is evaluated using this designed tool, which categorises it into one of the previously mentioned five levels (1, 2, 3, 4, or 5). As for transitioning between levels, this study does not aim to recommend specific actions. Instead, its purpose is to assess the municipality's level of smartness without prescribing any subsequent steps.

South African municipalities, including Matjhabeng Municipality, have the potential to be smarter than they currently are compared to the rest of Africa. However, of course, they are not as smart as Europe and other developed countries. The study selected, among six domains of the smart city concept, a smart environment, with a mobile application for waste management and reporting, to illustrate how different municipal departments can be improved by smart technology. To assist the municipality in advancing from the current level to a higher level, this example demonstrates how the municipal waste collection department's manual system was modernised through the implementation of an innovative waste management and reporting application. Therefore, this application serves as an example of how relevant projects for different municipal departments can be identified and initiated to deliver modernised, technological, and innovative solutions to their recognised challenges.

Several stages were involved in implementing the smart waste management mobile application, including data collection, user-friendly interface design, and robust data storage. Requesting waste collection vehicles, reporting illegal dumping and uncollected waste, providing real-time updates, and delivering feedback, among other tasks, are key processes that the application simplifies. To enable handling multiple requests, the application has been precisely designed and developed, and subjected to reliability and security testing to ensure its usability and security. Subsequently, both controlled experiments and real-time scenarios were successfully conducted for testing purposes.

The mobile application runs on Android. It requires an internet connection for users to log in, as the database verifies user accounts in real time. Users can access the application options menu after successful login. The application's user-friendliness is designed for users of all ages. In addition, to locate and track illegal dumping sites, the application integrates the Google Maps API. Through this feature, the municipality efficiently and effectively pinpoints areas requiring waste collection and truck dispatch. Currently, such information is manually gathered and disseminated through local newspapers.

7.4 Contribution of the Study

This study made a substantial contribution to knowledge in the field of smart cities and smartness assessment. Through a systematic review of several relevant works on smart city concepts, this study identified research gaps and developed a novel framework for measuring smartness. For instance, the study focused on exploring the sustainable consideration of a smartness-measuring framework in a developing municipality, a novel idea that had not been well-explored in this municipality and, most importantly, in the Free State region. Hence, this led to the conceptualisation of the framework by identifying the relevant and critical quantifying indicators for this municipality and by offering a measurement framework through the study's objectives. In implementing the smartness level, the study proposed the formulation and application of a metric to measure the smartness of the Matjhabeng Municipality, called the matrix levels. This metric was developed through an extensive literature review and the opinions of municipal top officials on how the six domains of smart cities inform the conceptualisation of the indicators utilised in the framework.

Based on a review of the existing literature in municipal smartness assessment, the study contributed significantly to this field by incorporating identified indicators into the framework and proposing ways to evaluate it using the Trapezoidal function, FSE, and MCDM, as formulated in Chapter 5. A better representation of data sources eliminated data inconsistencies and created a unified, well-presented data format using the proposed framework. A discussion of the proposed framework implementation and presentation is found in Chapter 4. Furthermore, the study used mobile app technology to develop an application to enhance waste transportation and collection, illegal dumping reporting, and seamless communication between the municipality and community members. While the other studies have contributed to the study of ITC concerning mobile apps, none of the studies have focused on developing a waste management mobile application for Matjhabeng Municipality; thus, the study is unique in the sense that it argues for the use of this mobile app to ensure a better quality of life for citizens of this municipality. Chapter 6 provides an overview of the mobile application.

In summary, this study contributed substantially to understanding the measurement of smartness status in municipal settings, thereby providing valuable insights for decision-makers in future development activities. The study approach can also be adapted for replication in further studies. In addition to findings, conceptual diagrams, reviews, analyses, methods, discussions, and conclusions, this work adds significant value to the body of knowledge on the concept of smart cities.

7.5 Future Areas of Research

The research has made significant progress in key areas of the study's framework; however, many areas warrant further exploration. Based on this research, researchers could examine the municipality’s role in smartness success and the factors that contribute to smartness failure within municipalities by analysing the municipality's impact on smartness projects. Researchers may wish to apply this assessment framework in practice and examine its limitations that may have been missed during implementation. They may also want to explore and evaluate the framework in other South African municipalities and refine indicators for the domains not covered by this framework. The framework has the potential to be enhanced and adapted through practical implementation, and others can also make significant suggestions and enhancements to improve its effectiveness.

It might be other researchers' desire to develop technological systems across different domains of the framework to improve municipal services for the community they serve. Furthermore, such an initiative could be extended to developing software applications for other municipal departments that may need improvement.

In conclusion, as highlighted in Chapter 5, to further utilise entropy weights and compare critical indicators across all domains of this study requires a statistical treatment of weightings, particularly the reliance on domain comparisons. Although systematic, this method risks oversimplifying or obscuring local priorities. Future studies should therefore adopt context-sensitive weighting frameworks that integrate statistical analysis with participatory methods involving municipal stakeholders and community members. This would ensure that the framework remains scientifically rigorous while also aligning with the municipality's developmental realities.

7.6 Conclusion

As the national government expects a return on investment from its municipalities in terms of measuring smartness status and success, municipalities across South Africa are eagerly anticipating this performance measure. Using this research, it was found that Matjhabeng Municipality has achieved a smartness performance rate of 3.2409. According to this overall smartness development index, the municipality has made advanced progress in adopting smart practices. The research was conducted to develop not just a mere framework, but a prevailing assessment framework capable of measuring the smartness performance of this municipality and others. It has become clear throughout South Africa that smartness measurement is a necessity and an essential component of any developed and/or developing municipality. However, the transition has not been smooth; challenges have been encountered during the study, but learning from other researchers' work has been invaluable. Based on the results of this study, six key domains have been identified as the critical components of a SAF: Smart Governance, Smart Economy, Smart People, Smart Living, Smart Environment, and Smart Mobility. Neither the study nor the framework seeks to improve the municipality's level of smartness. However, the objective has been to measure the municipality's smartness and provide the results; plans to exploit those results are the municipality's prerogative.

The proposed framework corroborates findings in the existing literature on the conditions necessary for assessment framework success, including consideration of appointed employees and administrators, as well as elected political officials. Based on the domain analysis in the proposed framework, it is discouraging that citizens in the municipality are dissatisfied with the services provided by the municipality. Better service-delivery approaches should be pursued to address the situation. Smartness status has thus been the topic of several studies globally.

A measurement framework such as SAF is a key to Matjhabeng Municipality and others in their journey to discovering smartness performance, and its adoption might pave the way for examining overall performance. The alignment of the framework indicators with internationally recognised standards from bodies such as ISOs has attested to their effectiveness and reliability. Lessons learned from this study include the data generated by the statistical results, which position the municipality at an intermediate level of smartness. Nonetheless, it has been previously stated that this research does not propose possible smartness solutions to the municipality's challenges, but instead assesses, analyses, and provides an overall assessment of smartness.

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Central University of Technology, Free State

APPENDICES

APPENDIX A:

38 Nathaniel Drive
Riebeeckstad
Welkom
9459

September 2023

Dear Participant

My name is **Moabi Saul Kompi** and I am a registered postgraduate PhD student at Central University of Technology, Free State, under the supervision of Professor Muthoni Masinde.

The title of my research is **"An internet of things framework for smart city implementation in South Africa's municipalities: case study of Matjhabeng Local Municipality".** The purpose of this letter is to kindly request you to participate in this research study, by voluntarily agreeing to be interviewed.

I wish to confirm the following before we start with the interview:

- You are more than welcome to withdraw from this discussion any time if you do not feel the need to continue with the completion.
- The information you provide will ONLY be used for research purposes in line with my PhD studies.
- Please remember that there are no right or wrong answers. We are interested in your opinions and experiences.
- The confidentiality of this conversation is guaranteed, and you will not be requested to provide any personal details.
- A copy of the completed report will be made available to you upon reasonable request.
- Should you encounter any ambiguity or have any enquiries regarding this interview, please feel free to contact me on the following: mkompi@cut.ac.za Or my supervisor on emasinde@cut.ac.za.

Your time and honest response are much appreciated.

Thank you!

Mr MS Kompi

MUNICIPALITY INTERVIEW GUIDE ON SMART CITIES

1. What steps will be taken to ensure healthcare professionals well-being and work-life balance are not compromised by expanded hours and increased staffing?
2. What strategies do you have in place to ensure routine facility maintenance tasks are not overlooked and carried out efficiently?
3. How does the municipality promote and support sports, arts, and culture festivals on a regular basis?
4. With the additional police stations and IoT infrastructure, how do you anticipate the municipality's approach to crime prevention and public safety will evolve in the coming years?
5. Would you please tell me how your plan is to address the skills gap that might be hindering young people from finding suitable jobs?
6. How do you involve youth in economic development and employment decision-making?
7. What can you do to create a supportive and thriving business ecosystem for small businesses?
8. What are the municipality's long-term goals and vision for the mining industry, and how do you plan to achieve sustainable growth?
9. As transportation demands evolve, how will the municipality encourage innovative improvements within the taxi industry?
10. Are there any plans to collaborate with educational institutions or research centres to support research and development initiatives that may attract investors in cutting-edge industries?
11. In what ways does the municipality encourage and support the development of skills and knowledge among its administrative, political, and community members?
12. What strategies are employed to retain skilled and trained employees within the municipality, especially in competitive job markets?
13. How are residents being assisted in overcoming unemployment and finding employment?
14. With only 409 people holding master's degrees and 295 with doctoral degrees (PhD), what measures are in place to encourage and support further education within the municipality?
15. To what extent are strategies being implemented in the municipality to improve access to higher education for residents and to promote lifelong learning?
16. Is there any advantage of flats, townhouses, and social housing in terms of reducing the need for private vehicles and promoting alternative transportation options such as public transit, walking, and biking?
17. Are there any plans to implement an Intelligent Public Transportation System?
18. To ensure that water management efforts benefit all residents, including marginalized and underserved groups, what strategies are being used?
19. How does the municipality plan to investigate the use of waste-to-energy and gas as potential solutions to reduce waste in landfill sites?

20. How will the municipality ensure that the workforce responsible for infrastructure maintenance and repairs is adequately trained and equipped to handle aging systems challenges?
21. Are there any plans to promote renewable energy sources, such as solar or wind power, to supplement the existing energy supply?
22. How are the key projects identified in the Integrated Development Plan (IDP), and how does the public participation process influence the selection of these projects?
23. What plans are in place to reach out to underrepresented communities to ensure their voices are heard during public participation and considered in decision-making processes?
24. How has the implementation of ICT infrastructure in a municipality positively impacted residents, businesses, and government operations?
25. What strategies are being employed to ensure Wi-Fi access is affordable and accessible to businesses and residents, including those in underserved areas?
26. How does the municipality ensure that these fire stations are adequately staffed with trained firefighters and equipped with modern firefighting equipment?

Central University of Technology, Free State

APPENDIX B:

Central University of Technology, Free State

FACULTY OF ENGINEERING, BUILT ENVIRONMENT & IT (FEBIT)

DEPARTMENT OF INFORMATION TECHNOLOGY

18 October 2022

The Municipal Manager
Matjhabeng Municipality
PO Box 708,
Welkom,
9460

Request for permission to conduct research based interview with employees of the Municipality

Dear Ms Zingisa Tindleni,
I am writing to confirm that **Mr Moabi Saul Kompi (Student# 9613056**) is currently registered for PhD in Information Technology qualification at Central University of Technology, Free State.

Mr Kompi's approved research topic is " ***An internet of things framework for smart city implementation in South Africa's municipalities: case study of Matjhabeng Local Municipality***" and I am his supervisor. I also confirm that he has completed his literature review and drafted the data collection instruments (an interview guide and a questionnaire). Before he can finalize these tools and submit them for ethical clearance by the University, Mr Kompi requires some general information relating to the implementation of Smart City Concept in Matjhabeng Local Municipality.

With this memo, I am kindly requesting your permission to allow relevant members of your institution to provide the above information to Mr Kompi through a voluntarily interview setting. I wish to assure you that the information provided will ONLY be used for research purposes in line with the PhD studies. Besides, the confidentiality of this interview is guaranteed, and the participating staff members will not be requested to provide any personal details.

I am looking forward to response and for a long-term engagement with your Office.

Yours sincerely,

Central University of Technology, Free State

Prof Muthoni Masinde
Professor and Head of Department
Department of Information Technology
Faculty of Engineering, Built Environment and Information Technology
E: emasinde@cut.ac.za | **T:** +27 51 507 3091
www.cut.ac.za

Vision 2030
The Central University of Technology. Shaping the future through innovation as a leading African University of Technology

APPENDIX C

Municipality
Umasipala
P O Box 708
Welkom, 9460
South Africa

MATJHABENG

Mmasepala
Munisipaliteit
Tel: (057) 391 3711
Fax: (057) 357 4393
E-mail: mm@matjhabeng.co.za

OFFICE OF THE MUNICIPAL MANAGER

Enquiries/Navrae/DipatIisi	• Dr. V Adonis
Room no/ Kamer nrl Kamore ya	• Room 212, 2 nd Floor
Datel Datum/Letsatsi	• 05 December 2022

Central University of Technology FS
Faculty Of Engineering, Built Environment & Information
Welkom Campus
9460

Attention: Prof Muthoni Masinde

REQUEST FOR PERMISSION TO CONDUCT RESEARCH BASED INTERVIEW WITH EMPLOYEES OF MATJHABENG LOCAL MUNICIPALITY

The above matter refers.

The office of the Municipal Manager herewith acknowledge receipt of your letter dated 18th of October 2022 requesting permission to conduct research and note the contents thereof. The Municipality herewith grant permission to conduct the research.

For further clarity please don't hesitate to contact Dr. Vuyo Adonis @ 066 188 2884 email address vuyo.adonis@matjhabeng.co.za

I hope that you will find all of the above in order.

Yours faithfully

Dr. VUYO ADONIS
ACTING MUNICIPAL MANAGER

APPENDIX D

APPLICATION FORM FOR ETHICAL CLEARANCE: FEBIT

I declare that all statements made in this application are true and accurate. I accept the conditions associated with the granting of approval to conduct research and undertake to abide by them.	
STUDENT SIGNATURE / PROJECT LEADER SIGNATURE / SIGNATURE OF RESEARCHER	
DATE	07 August 2023

7. DECLARATION BY SUPERVISOR(S) (where applicable)

I/we declare that I/we shall oversee the student's adherence to all statements as set out above.	
SIGNATURE (Main supervisor)	
SIGNATURE (Co-supervisor)	
DATE	08 August 2023

FOR OFFICIAL USE

APPROVAL OF FEBIT ETHICAL COMMITTEE (FRIC)

Please tick relevant decision and provide conditions/reasons where applicable		
Decision		Please tick relevant option
1.	Application approved	
2.	Ethical clearance number FRIC:06/09/2023(1)	
3.	Application approved subject to certain conditions. Specifr conditions below	
4.	Application not approved. Provide reasons for non-approval below	
SIGNATURE: Chairperson: Ethics committee		
DATE	06/09/2023	

cc Dean: FEBIT

APPENDIX E

Overview of Android Program Segment of the Registration Page Code Module

```
public class Register extends AppCompatActivity {
 Button btnRegister;
 EditText etRegisterName, etRegisterSurname, etRegisterId, etRegisterPassword, etRegisterRePassword,
 etRegisterEmail,etRegisterCellphone,etRegisterAddress;
 private View mProgressView;
 private View mLoginFormView;
 private TextView tvLoad;
 String rolePermanent = " ";
 @Override
 protected void onCreate (Bundle savedInstanceState) {
   super.onCreate(savedInstanceState);
   setContentView(R.layout.activity_register);
   btnRegister = findViewById(R.id.btnRegisterRegister);
   etRegisterName = findViewById(R.id.etRegisterName);
   etRegisterSurname = findViewById(R.id.etRegisterSurname);
   etRegisterId = findViewById(R.id.etRegisterId);
   etRegisterPassword = findViewById(R.id.etRegisterPassword);
   etRegisterRePassword = findViewById(R.id.etRegisterRePassword);
   etRegisterEmail = findViewById(R.id.etRegisterEmail);
   mProgressView = findViewById(R.id.login_progress);
   tvLoad = findViewById(R.id.tvLoad);
   etRegisterAddress=findViewById(R.id.etRegisterAddressReg);
   mLoginFormView = findViewById(R.id.login_form);
   etRegisterCellphone= findViewById(R.id.etRegisterCellphone);
   getSupportActionBar().setDisplayHomeAsUpEnabled(true);
   setTitle("Register");
   btnRegister.setOnClickListener(new View.OnClickListener() {
    @Override
    public void onClick (View view) {
     if (etRegisterName.getText().toString().isEmpty() || etRegisterAddress.getText().toString().isEmpty() ||
      etRegisterSurname.getText().toString().isEmpty() || etRegisterId.getText().toString().isEmpty()) {
      Toast.makeText(Register.this, "Fill in blank fields!", Toast.LENGTH_SHORT).show();
     } else {
       if (etRegisterPassword.getText().length() > 0 && etRegisterRePassword.getText().toString().length() > 0) {
        if (etRegisterPassword.getText().toString().equals(etRegisterRePassword.getText().toString())) {
          tvLoad.setText("Registering User...Please wait...");
          showProgress(true);
          BackendlessUser user = new BackendlessUser();
          user.setProperty("name", etRegisterName.getText().toString());
          user.setProperty("surname", etRegisterSurname.getText().toString());
          user.setProperty("id", etRegisterId.getText().toString());
          user.setProperty("email", etRegisterEmail.getText().toString().toLowerCase());
          user.setPassword(etRegisterRePassword.getText().toString());
          user.setProperty("address",etRegisterAddress.getText().toString());
```

```
if (etRegisterEmail.getText().toString().toLowerCase().contains("@municipality.com") ||
  etRegisterEmail.getText().toString().toLowerCase().contains("@municipality.co.za"
  || etRegisterEmail.getText().toString().toLowerCase().contains("@municipality.gov.za")) {
  user.setProperty("role", "admin");
  rolePermanent = "admin";
} else {
  user.setProperty("role", "community");
  rolePermanent = "community";
}
user.setProperty("cellphone", etRegisterCellphone.getText().toString());
Backendless.UserService.register(user, new AsyncCallback<BackendlessUser>() {
  @Override
  public void handleResponse (BackendlessUser response) {
    Toast.makeText(Register.this, "Member successfully registered!", Toast.LENGTH_SHORT).show();
    showProgress(false);
    finish();
    if (rolePermanent.equals("admin")) {
      Intent i = new Intent (Register.this, home_admin.class);
      i.putExtra ("role", "admin");
      i.putExtra ("name", etRegisterName.getText().toString());
      i.putExtra ("surname", etRegisterSurname.getText().toString());
      i.putExtra("id", etRegisterId.getText().toString());
      i.putExtra("cellphone", etRegisterCellphone.getText().toString());
      i.putExtra("email", etRegisterEmail.getText().toString());
      i.putExtra("password", etRegisterRePassword.getText().toString());
      i.putExtra("address", etRegisterAddress.getText().toString());
      startActivity(i);
    } else {
      Intent b = new Intent(Register.this, HomeActivity.class);
      b.putExtra("role", "community");
      b.putExtra("name", etRegisterName.getText().toString());
      b.putExtra("surname", etRegisterSurname.getText().toString());
      b.putExtra("id", etRegisterId.getText().toString());
      b.putExtra("cellphone", etRegisterCellphone.getText().toString());
      b.putExtra("email", etRegisterEmail.getText(). toString());
      b.putExtra("password", etRegisterRePassword.getText().toString());
      b.putExtra("address", etRegisterAddress.getText().toString());
      startActivity(b);
    }
    etRegisterName.setText("");
    etRegisterSurname.setText("");
    etRegisterId.setText("");
    etRegisterPassword.setText("");
    etRegisterRePassword.setText("");
    etRegisterEmail.setText("");
    etRegisterCellphone.setText("");
  }
  @Override
  public void handleFault (BackendlessFault fault) {
    Toast.makeText(Register.this, fault.getMessage(), Toast.LENGTH_SHORT).show();
```

```
                showProgress(false);
              }
            });
          } else {
            Toast.makeText(Register.this, "Passwords don't match.Re-type passwords",
                        Toast.LENGTH_LONG).show();
            etRegisterPassword.setText("");
            etRegisterRePassword.setText("");
          }
        } else {
          Toast.makeText(Register.this, "One of the passwords field is blank!", Toast.LENGTH_LONG).show();
        }
      }
    }
  });
}
```

APPENDIX F

Overview of Android Program Segment of the Status Report List Code Module

```
If (role.equals ("admin"))
 {
   tvLoad.setText("Loading Reports...Please Wait");
   showProgress(true);
   Backendless.Data.of(Waste.class).find (new AsyncCallback<List<Waste>>() {
    @Override
    public void handleResponse (List<Waste> response) {
      if (response.size () > 0)
       {
        responseBack = response;
        ViewIssueStatusAdapteradapter = new ViewIssueStatusAdapter (StatusReportList.this, response);
        listReport.setAdapter(adapter);
        showProgress(false);
       }
       showProgress(false);
     }
     @Override
      public void handleFault (BackendlessFault fault) {Toast.makeText(StatusReportList.this,fault.getMessage (),
                                  Toast.LENGTH_SHORT).show();
       showProgress(false);
      }
     });
   }
   else
   {
     tvLoad.setText("Loading Reports...Please Wait");
     showProgress(true);
     Backendless.Data.of(Waste.class).find(queryBuilder,new AsyncCallback<List<Waste>>() {
      @Override
      public void handleResponse (List<Waste> response) {
        if(response.size() > 0)
        {
          responseBack = response;
          ViewIssueStatusAdapter adapter = new ViewIssueStatusAdapter(StatusReportList.this,response);
          listReport.setAdapter(adapter);
          showProgress(false);
        }
        showProgress(false);
      }
      @Override
      public void handleFault (BackendlessFault fault) {
        Toast.makeText(StatusReportList.this, fault.getMessage(), Toast.LENGTH_SHORT).show();
        showProgress(false);
      }
     });
   }
listReport.setOnItemLongClickListener (new AdapterView.OnItemLongClickListener() {
```

```
  @Override
  public boolean onItemLongClick (AdapterView<?> adapterView, View view, int i, long l) {
    if(role.equals("admin")) {
      if (responseBack.get(i).getStatus().toString().equals("no progress")) {
        showAlertDialog (0, i);
      } else if (responseBack.get(i).getStatus().toString().equals("in progress")) {
        showAlertDialog (1, i);
      } else if ((responseBack.get(i).getStatus().toString().equals("completed"))) {
        showAlertDialog(2, i);
      }
    }
    return true;
  }
});
    listReport.setOnItemClickListener(new AdapterView.OnItemClickListener() {
      @Override
      public void onItemClick (AdapterView<?> adapterView, View view, int i, long l) {
        String geoUri = "http://maps.google.com/maps?q=loc:" + responseBack.get(i).latu.toString () + "," +
        responseBack.get(i).longi.toString () + " (place)";
        Intent intent = new Intent (Intent.ACTION_VIEW, Uri.parse(geoUri));
        startActivity(intent);
      }
    });
```

APPENDIX G

Integrated Min-Max Normalization + Trapezoidal Fuzzy Synthetic Evaluation

```
function SmartCityssessment()
%% Comprehensive Smart City Assessment
% Integrated Min-Max Normalization + Trapezoidal Fuzzy Synthetic Evaluation
% Developed for Smart City Dimension Analysis

clear; clc; close all;

%% 1. INPUT DATA - Smart City Dimensions
fprintf('=== SMART CITY ASSESSMENT ANALYSIS ===\n\n');

% Raw data for each dimension
SG = [10, 70, 44, 1, 19, 30, 60, 71, 51, 54];      % Smart Governance
SE = [56, 28, 56, 50, 81, 2, 60];                  % Smart Economy
SP = [38, 9, 70, 60];                             % Smart People
SL = [52, 5, 60, 29];                             % Smart Living
Sen = [2, 81, 46, 1, 41, 46, 54, 51, 1, 38];      % Smart Environment
SM = [5, 10];                                     % Smart Mobility

dimension_names = {'Smart Governance', 'Smart Economy', 'Smart People', ...
                  'Smart Living', 'Smart Environment', 'Smart Mobility'};
dimension_data = {SG, SE, SP, SL, Sen, SM};

%% 2. MIN-MAX NORMALIZATION
fprintf('=== STEP 1: MIN-MAX NORMALIZATION ===\n');

% Combine all data for normalization
all_data = [SG, SE, SP, SL, Sen, SM];

% Calculate statistics
data_min = min(all_data);
data_max = max(all_data);

fprintf('Statistics for Normalization:\n');
fprintf('Minimum: %.4f\n', data_min);
fprintf('Maximum: %.4f\n', data_max);
fprintf('Range: %.4f\n\n', data_max - data_min);

% Min-Max Normalization function: x_norm = (x - min) / (max - min)
normalize_data = @(x) (x - data_min) / (data_max - data_min);

% Apply normalization to each dimension
normalized_dims = cell(1, 6);
for i = 1:6
    normalized_dims{i} = arrayfun(normalize_data, dimension_data{i});
end

% Display normalized results
fprintf('Min-Max Normalized Dimension Scores (0-1 scale):\n');
for i = 1:6
```

```
    fprintf('%s: [', dimension_names{i});
    fprintf('%.4f ', normalized_dims{i});
    fprintf(']\n');
end
fprintf('\n');

%% 3. TRAPEZOIDAL FUZZY NUMBER DEFINITION
fprintf('=== STEP 2: TRAPEZOIDAL FUZZY SETUP ===\n');

% Define linguistic variables and trapezoidal fuzzy numbers
linguistic_levels = {'Not Developed', 'Least Developed', 'Fairly Developed', ...
                    'Developed', 'Very Developed'};
scale_values = [1, 2, 3, 4, 5];

% Trapezoidal fuzzy numbers [a, b, c, d] on 0-1 scale
trapezoidal_sets = [
    0.0, 0.0, 0.1, 0.3;    % Not Developed
    0.1, 0.3, 0.4, 0.5;    % Least Developed
    0.4, 0.5, 0.6, 0.7;    % Fairly Developed
    0.6, 0.7, 0.8, 0.9;    % Developed
    0.8, 0.9, 1.0, 1.0     % Very Developed
];

fprintf('Trapezoidal Fuzzy Numbers (0-1 scale):\n');
for i = 1:5
    fprintf('%s: (%.1f, %.1f, %.1f, %.1f)\n', ...
        linguistic_levels{i}, trapezoidal_sets(i,:));
end
fprintf('\n');

%% 4. EXPERT RATING DISTRIBUTION MAPPING
fprintf('=== STEP 3: EXPERT RATING DISTRIBUTION ===\n');

% Function to map normalized scores to expert ratings
function ratings = map_to_expert_ratings(norm_score)
    if norm_score < 0.2
        ratings = [0.40, 0.45, 0.10, 0.05, 0.00];  % Very poor - High ND
    elseif norm_score < 0.4
        ratings = [0.25, 0.45, 0.20, 0.08, 0.02];  % Poor - High LD
    elseif norm_score < 0.6
        ratings = [0.10, 0.20, 0.45, 0.20, 0.05];  % Fair - High FD
    elseif norm_score < 0.8
        ratings = [0.07, 0.17, 0.32, 0.30, 0.14];  % Good - Balanced D/FD
    else
        ratings = [0.05, 0.15, 0.25, 0.35, 0.20];  % Excellent - High D/VD
    end
end

% Generate expert ratings for all dimensions
expert_ratings = cell(1, 6);
for i = 1:6
```

```
    dim_ratings = zeros(length(normalized_dims{i}), 5);
    for j = 1:length(normalized_dims{i})
        dim_ratings(j, :) = map_to_expert_ratings(normalized_dims{i}(j));
    end
    expert_ratings{i} = dim_ratings;
end

% Display sample expert ratings
fprintf('Sample Expert Rating Distributions:\n');
fprintf('First 3 indicators of Smart Governance:\n');
for j = 1:3
    fprintf('SG%d (norm=%.4f): [', j, normalized_dims{1}(j));
    fprintf('%.3f ', expert_ratings{1}(j, :));
    fprintf(']\n');
end
fprintf('\n');

%% 5. WEIGHT CALCULATION
fprintf('=== STEP 4: WEIGHT CALCULATION ===\n');

% Calculate weights for each dimension
dimension_weights = zeros(1, 6);
dimension_sums = zeros(1, 6);

for i = 1:6
    dimension_sums(i) = sum(dimension_data{i});
end

total_sum = sum(dimension_sums);
dimension_weights = dimension_sums / total_sum;

fprintf('Dimension Weights:\n');
for i = 1:6
    fprintf('%s: %.4f (Sum: %d)\n', dimension_names{i}, dimension_weights(i),
dimension_sums(i));
end
fprintf('Total Sum: %d\n', total_sum);
fprintf('Sum of weights: %.4f\n\n', sum(dimension_weights));

% Calculate indicator weights for each dimension
indicator_weights = cell(1, 6);
for i = 1:6
    dim_data = dimension_data{i};
    dim_sum = sum(dim_data);
    indicator_weights{i} = dim_data / dim_sum;

    fprintf('%s Indicator Weights: [', dimension_names{i});
    fprintf('%.4f ', indicator_weights{i});
    fprintf('] Sum: %.4f\n', sum(indicator_weights{i}));
end
fprintf('\n');
```

```
%% 6. FUZZY SYNTHETIC EVALUATION
fprintf('=== STEP 5: FUZZY SYNTHETIC EVALUATION ===\n');

% Function to perform FSE for a dimension
function [Z, development_index] = perform_fse(weights, expert_ratings)
    % Z = W ⊗ Y (fuzzy composite operation)
    Z = zeros(1, 5);
    for level = 1:5
        Z(level) = sum(weights .* expert_ratings(:, level)');
    end

    % Normalize Z to ensure sum = 1
    Z = Z / sum(Z);

    % Calculate development index: Z × E
    development_index = sum(Z .* [1, 2, 3, 4, 5]);
end

% Perform FSE for each dimension
dimension_Z = cell(1, 6);
development_indices = zeros(1, 6);

fprintf('Dimension-Level FSE Results:\n');
fprintf('%-20s %-12s %-15s\n', 'Dimension', 'Raw Sum', 'Development Index');
for i = 1:6
    weights = indicator_weights{i};
    ratings = expert_ratings{i};
    [dimension_Z{i}, development_indices(i)] = perform_fse(weights, ratings);

    fprintf('%-20s %-12d %-15.4f\n', dimension_names{i}, dimension_sums(i), development_indices(i));
end
fprintf('\n');

% Display detailed fuzzy vectors
fprintf('Detailed Fuzzy Vectors:\n');
for i = 1:6
    fprintf('%s: [', dimension_names{i});
    fprintf('%.4f ', dimension_Z{i});
    fprintf('] Sum: %.4f\n', sum(dimension_Z{i}));
end
fprintf('\n');

%% 7. OVERALL SMART CITY ASSESSMENT
fprintf('=== STEP 6: OVERALL ASSESSMENT ===\n');

% Construct overall fuzzy matrix
overall_Y = zeros(6, 5);
for i = 1:6
    overall_Y(i, :) = dimension_Z{i};
```

```
end

% Calculate overall fuzzy evaluation: Z_overall = W_overall ⊗ Y_overall
overall_Z = zeros(1, 5);
for level = 1:5
    overall_Z(level) = sum(dimension_weights .* overall_Y(:, level)');
end

% Normalize overall Z
overall_Z = overall_Z / sum(overall_Z);

% Calculate overall development index
overall_index = sum(overall_Z .* [1, 2, 3, 4, 5]);

fprintf('Overall Smart City Assessment:\n');
fprintf('Overall Development Index: %.4f\n', overall_index);
fprintf('Status: %s\n', get_development_status(overall_index));
fprintf('Fuzzy Vector: [');
fprintf('%.4f ', overall_Z);
fprintf('] Sum: %.4f\n\n', sum(overall_Z));

%% 8. VISUALIZATION
fprintf('=== STEP 7: VISUALIZATION ===\n');

% Create figure with multiple subplots
figure('Position', [100, 100, 1400, 900]);

% Plot 1: Dimension Comparison (Bar Chart)
subplot(2, 3, 1);
bars = bar(development_indices, 'FaceColor', [0.2, 0.6, 0.8]);
set(gca, 'XTickLabel', dimension_names, 'XTickLabelRotation', 45);
title('Smart City Dimension Development Indices', 'FontSize', 12, 'FontWeight', 'bold');
ylabel('Development Index');
ylim([1, 5]);
grid on;

% Add value labels on bars
for i = 1:length(development_indices)
    text(i, development_indices(i) + 0.1, sprintf('%.3f', development_indices(i)), ...
        'HorizontalAlignment', 'center', 'FontWeight', 'bold');
end

% Plot 2: Fuzzy Membership Functions
subplot(2, 3, 2);
x = 0:0.01:1;
colors = ['r', 'g', 'b', 'm', 'c'];
for i = 1:5
    a = trapezoidal_sets(i, 1);
    b = trapezoidal_sets(i, 2);
    c = trapezoidal_sets(i, 3);
    d = trapezoidal_sets(i, 4);
```

```

    y = zeros(size(x));
    y(x >= a & x < b) = (x(x >= a & x < b) - a) / (b - a);
    y(x >= b & x <= c) = 1;
    y(x > c & x <= d) = (d - x(x > c & x <= d)) / (d - c);

    plot(x, y, 'Color', colors(i), 'LineWidth', 2.5);
    hold on;
end
legend(linguistic_levels, 'Location', 'northeast', 'FontSize', 9);
title('Trapezoidal Membership Functions', 'FontSize', 12, 'FontWeight', 'bold');
xlabel('Development Level (0-1 scale)');
ylabel('Membership Degree');
grid on;

% Plot 3: Overall Fuzzy Distribution
subplot(2, 3, 3);
bar(overall_Z, 'FaceColor', [0.8, 0.4, 0.2]);
set(gca, 'XTickLabel', linguistic_levels, 'XTickLabelRotation', 45);
title('Overall Smart City Fuzzy Distribution', 'FontSize', 12, 'FontWeight', 'bold');
ylabel('Membership Degree');
ylim([0, 0.5]);
grid on;

% Add value labels on bars
for i = 1:length(overall_Z)
    text(i, overall_Z(i) + 0.02, sprintf('%.3f', overall_Z(i)), ...
        'HorizontalAlignment', 'center', 'FontWeight', 'bold');
end

% Plot 4: Radar Chart for Dimensions
subplot(2, 3, 4);
radar_data = [development_indices, development_indices(1)];
angles = linspace(0, 2*pi, 7);
polarplot(angles, radar_data, 'LineWidth', 3, 'Marker', 'o', 'MarkerSize', 6);
title('Smart City Dimension Radar Chart', 'FontSize', 12, 'FontWeight', 'bold');
legend('Development Levels', 'Location', 'best');

% Plot 5: Weight Distribution
subplot(2, 3, 5);
pie(dimension_weights, dimension_names);
title('Dimension Weight Distribution', 'FontSize', 12, 'FontWeight', 'bold');

% Plot 6: Normalized Scores Distribution
subplot(2, 3, 6);
all_normalized = [normalized_dims{:}];
histogram(all_normalized, 10, 'FaceColor', [0.4, 0.8, 0.4], 'EdgeColor', 'black');
title('Distribution of Min-Max Normalized Scores', 'FontSize', 12, 'FontWeight', 'bold');
xlabel('Normalized Score (0-1)');
ylabel('Frequency');
grid on;
```

```

% Add overall result annotation
sgtitle(sprintf('Smart City Assessment - Overall Index: %.4f (%s)', ...
    overall_index, get_development_status(overall_index)), ...
    'FontSize', 14, 'FontWeight', 'bold', 'Color', [0, 0.4, 0]);

%% 9. DETAILED RESULTS OUTPUT
fprintf('=== STEP 8: DETAILED RESULTS ===\n\n');

fprintf('DIMENSION-WISE DETAILED ANALYSIS:\n');
fprintf('=================================\n\n');

for i = 1:6
    fprintf('%s ANALYSIS:\n', dimension_names{i});
    fprintf('Raw Scores: [');
    fprintf('%d ', dimension_data{i});
    fprintf(']\n');

    fprintf('Min-Max Normalized: [');
    fprintf('%.4f ', normalized_dims{i});
    fprintf(']\n');

    fprintf('Average Normalized Score: %.4f\n', mean(normalized_dims{i}));

    fprintf('Indicator Weights: [');
    fprintf('%.4f ', indicator_weights{i});
    fprintf(']\n');

    fprintf('Fuzzy Vector: [');
    fprintf('%.4f ', dimension_Z{i});
    fprintf(']\n');

    fprintf('Development Index: %.4f\n', development_indices(i));
    fprintf('Status: %s\n\n', get_development_status(development_indices(i)));
end

fprintf('OVERALL SMART CITY ASSESSMENT:\n');
fprintf('=============================\n');
fprintf('Overall Development Index: %.4f\n', overall_index);
fprintf('Overall Status: %s\n', get_development_status(overall_index));
fprintf('Fuzzy Distribution:\n');
for i = 1:5
    fprintf('  %s: %.4f\n', linguistic_levels{i}, overall_Z(i));
end

% Calculate dimension rankings
[~, ranking] = sort(development_indices, 'descend');

fprintf('\nDIMENSION RANKING:\n');
fprintf('=================\n');
for i = 1:6
```

```
    rank = find(ranking == i);
    fprintf('%d. %s (Index: %.4f)\n', rank, dimension_names{i}, development_indices(i));
end

fprintf('\nRECOMMENDATIONS:\n');
fprintf('================\n');
[~, sorted_idx] = sort(development_indices, 'ascend');
fprintf('PRIORITY AREAS FOR IMPROVEMENT:\n');
for i = 1:3
    dim_idx = sorted_idx(i);
    fprintf('%d. %s (Index: %.4f, Status: %s)\n', i, dimension_names{dim_idx}, ...
            development_indices(dim_idx),
get_development_status(development_indices(dim_idx)));
end

fprintf('\nSTRONGEST DIMENSIONS:\n');
for i = 4:6
    dim_idx = sorted_idx(i);
    fprintf('%d. %s (Index: %.4f, Status: %s)\n', i-3, dimension_names{dim_idx}, ...
            development_indices(dim_idx),
get_development_status(development_indices(dim_idx)));
end

%% 10. NORMALIZATION VERIFICATION
fprintf('\n=== STEP 9: NORMALIZATION VERIFICATION ===\n');
fprintf('Min-Max Normalization Formula: x_norm = (x - %.1f) / (%.1f - %.1f)\n', ...
    data_min, data_max, data_min);
fprintf('Normalization Range: [%.1f, %.1f] -> [0, 1]\n', data_min, data_max);

% Verify normalization
fprintf('\nNormalization Verification:\n');
test_values = [data_min, data_max, 50]; % Test min, max, and middle value
for i = 1:length(test_values)
    norm_val = normalize_data(test_values(i));
    fprintf('x = %6.1f -> x_norm = %.4f\n', test_values(i), norm_val);
end

%% 11. HELPER FUNCTIONS
function status = get_development_status(index)
    if index < 1.5
        status = 'Not Developed';
    elseif index < 2.5
        status = 'Least Developed';
    elseif index < 3.5
        status = 'Fairly Developed';
    elseif index < 4.5
        status = 'Developed';
    else
        status = 'Very Developed';
    end
end
```

```
fprintf('\n=== ANALYSIS COMPLETE ===\n');

%% 12. EXPORT RESULTS (Optional)
% Create results table for export
results_table = table(dimension_names', dimension_sums', development_indices', ...
                     'VariableNames', {'Dimension', 'Raw_Sum', 'Development_Index'});

% Add normalized averages
normalized_avgs = cellfun(@mean, normalized_dims);
results_table.Normalized_Average = normalized_avgs';

% Add status
status_cell = arrayfun(@(x) get_development_status(x), development_indices, 'UniformOutput', false);
results_table.Status = status_cell';

fprintf('\nResults Table:\n');
disp(results_table);

% Uncomment to export to Excel
% writetable(results_table, 'smart_city_minmax_results.xlsx');
% fprintf('Results exported to smart_city_minmax_results.xlsx\n');

end
```