EXPLORING THE CHALLENGES TO DRONE-AIDED INSPECTIONS IN CONSTRUCTION SITE MANAGEMENT.

Dissertation

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DECLARATION

I declare that this dissertation is my own, unaided work. It is submitted for the degree of Master of Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other university.

Signature of Candidate:

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…26…. Day of …09……., ….2024……….

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ABSTRACT

The construction industry, marked by its complexity and evolving standards, demands attention and commitment to quality. To guarantee that works are going according to plan, standards and regulations, in terms of quality and compliance, routine inspection strategies are implemented as an intrinsic part of the project management plan. Construction inspections are generally performed as a contractual obligation to enable an independent view of construction works and their progress for key stakeholders and the client.

However, traditional inspection techniques are generally laborious and risky. Inspectors are often exposed to exterior elements; unfavourable conditions; intrinsic risks. Despite all of this, inspectors are still unable to obtain in-depth information on some of the surfaces due the inability to access surfaces or structures to optimal proximity. Drone technology has been proposed as an alternative method to traditional inspection for safer and more efficient inspections. This study endeavoured to explore key challenges to the implementation of drone technology for construction inspections.

The methodological approach that the researcher adopted to achieve the research aim encompassed a qualitative method with document analysis, case study and interviews selected as data collection strategies. Techniques to gather empirical information required included observations and semi-structured interview questions. To present findings that are valid, reliable and generalisable, NVivo software was used as a data analysis tool where content analysis and thematic analysis were employed as data analysis strategies. The utilisation of qualitative, inductive case studies within an interpretivist paradigm was considered necessary to contextualise and deepen the understanding of the nature and occurrence of the challenges impeding key role players from full adoption of drone technology for construction site inspection processes.

Key findings entail the lack of capital and resource allocation, concerns about transparency and contractual accountability, and the need for clear evidence of return on investment. Technical complexity, disruption to site activities, lack of interest from key stakeholders, capacity issues, and connectivity issues were also uncovered as challenges in the adoption of drone-aided inspections. Additionally, the findings encompassed strategies to overcome challenges impeding the optimal use of drones in construction projects. This study evaluates the current state and potential for drone technology adoption within the South African construction industry, highlighting practical challenges encountered during actual deployments. By proposing solutions such as streamlining regulatory processes and enhancing stakeholder collaboration, the research offers valuable pathways to optimise drone technology implementation during construction documentation and management.

KEYWORDS: drone technology; construction; inspections.

DEDICATION

I would like to dedicate this research to The Beautiful, The Bountiful, The Benevolent Almighty God of Mount Zion.

To my mother, Tshiwela Meriam Mudzusi

To my siblings, Norman, Masala, Itani, Beauty and Emmanuel.

To the Swanepoels, Jeanne, Hein, Heidi, Anje and Albert.

To Dr Murray Hofmeyr.

To Roshnee Guptar, my Oracle

To the dreamers and make-believers.

To myself.

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I would like to express my sincere appreciation to my mother for her love, hope and patience. Knowing you are my number one fan gave me so much courage and strength to make you proud. I would like to thank my siblings for their support in all aspects of my life while I focused on my schoolwork.

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LIST OF ABBREVIATIONS

Abbreviation	Description
4th IR	*Fourth Industrial Revolution*
AEC	*Architecture, Engineering and Construction*
AI	*Artificial Intelligence*
ASOCSA	*Association of Schools of Construction of Southern Africa*
BIM	*Building Information Modelling*
B-VlOS	*Beyond Visual Line-of-sight*
CDE	*Common Data Environment*
CIDB	*Construction Industry Development Board*
CM	*Construction Management*
CPM	*Construction Project Management*
CSM	*Construction Site Management*
DoI	*Diffusion of Innovations*
DT	*Drone Technology*
GIS	*Global Information System*
GPS	*Global Positioning System*
H&S	*Health and Safety*
HVAC	*Heating, Ventilation, and Air Conditioning*
ICAO	*International Civil Aviation Organization*
IoT	*Internet of Things*
ISO	*International Organization for Standardization*
LiDAR	*Light Detection and Ranging*
NDT	*Non-destructive Testing*
NHBRC	*National Home Builders Registration Council*
OSHA	*Occupational Health and Safety Administration*
PDA	*Personal Digital Assistant*
PMBOK	*Project Management Body of Knowledge*
PMI	*Project Management Institute*
R&D	*Research & Design*
RPAs	*remotely piloted aircrafts*
R-VLOS	*Restricted Visual Line-of-site*
SA	*South Africa*
SABS	*South African Bureau of Standards*
SACAA	*South African Civil Aviation Authority*
SACI	*South African Construction Industry*
SACPCMP	*South African Council for the Project and Construction ManagementProfession*
SACPM	*South African Construction Project Managers*
SANS	*South African National Standards*
SM	*Site Management*
TOE	*Technology-Organization-Environment*
UAS	*Unmanned Aerial System*
UAV	*unmanned aerial vehicles*
UGV	*Unmanned Ground Vehicle*

VLOS	*Visual Line-of-site*
WEF	*World Economic Forum*

CHAPTER 1: CONCEPTUALISING THE RESEARCH

1.1. Background

The integration of digital tools and applications is revolutionising project delivery methodologies and causing a dramatic transformation in the construction industry (Ibrahim *et al.*, 2022). Process problems such as capacity strain and variability are being addressed by implementing advanced software and construction-focused hardware, utilising digitisation, robotics, and automation technologies (Charlesraj and Rakshith, 2020; Pan *et al.*, 2020; Albeaino, Gheisari and Issa, 2022).

In contrast, the advent of digital technologies during the fourth industrial revolution has significantly altered the monolithic culture of the construction industry globally in an effort to meet the ever-increasing complexity of construction projects (Elia, Margherita and Secundo, 2020; Naveed and Khan, 2021; Razafimahazo *et al.*, 2021). Consequently, developments in IoT (Internet of Things), drone technology, Virtual Reality/Augmented Reality (VR/AR), construction robots, have evolved from model-based information enablers to increasingly intricate and comprehensive systems for data generation and management (Ram, Afridi and Khan, 2019; Osunsanmi *et al.*, 2020). The above mentioned emergent digital technologies have necessitated digital strategies among industry professionals within the built environment (Alaloul *et al.*, 2018, 2020).

Furthermore, out of necessity, the Covid-19 pandemic has forced the advancement toward digital convergence even for developing countries (Charlesraj and Rakshith, 2020; Patrick, Nnadi and Ajaelu, 2020). Digital technology adoption has major impacts on construction project value chain and productivity as well as fostering safe and sustainable construction activities (Woodhead, Stephenson and Morrey, 2018). Therefore, the implementation of intelligent digitisation and automation technologies within construction sites to optimise operational efficiency, mitigate cost over-runs and ensuring infrastructure and worker safety (Guan, Zhu and Wang, 2022).

One of above-mentioned promising technology that is earning wide adoption across the global construction industry is unmanned aerial systems, simply known as drone technology (Rakha and Gorodetsky, 2018; Guan, Zhu and Wang, 2022). Drone technology entails the use of unmanned aerial vehicles (UAVs) fitted with sensors and connected to remote devices via data link (Golizadeh, Hosseini, Martek, *et al.*, 2019). These are unmanned aircrafts that are remotely operated (Asnafi and Dastgheibifard, 2018; SACAA, 2021). Outay, Mengash and Adnan, (2020) explain that drones have been integrated with a variety of navigation systems, sensors, and monitoring systems to aid their manoeuvrability and high efficiency while minimising risks (Outay, Mengash and Adnan, 2020).

Within the construction site environment, drones aid the performance of a variety of tasks including site monitoring, infrastructure inspections and measuring surfaces and volumes without endangering the safety of the inspectors (Martinez, Gheisari and Alarcon, 2020). Similarly, they can serve as a real-time tool in project monitoring and tracking during project execution (Albeaino, Gheisari and Franz, 2019).

The use of UAVs dates to 1849 during the first Italian war of independence when unmanned hot air balloons were used by the Austrian Empire to drop bombs on Venice (Sanson, 2019). During the cold war, the U.S military advanced drone use through unmanned aerial systems research programs (Nooralishahi *et al.*, 2021). Commercial and model production was revolutionized by Da-Jiang Innovation Technologies Co (DJI) in the late 2000s with the introduction of the DJI phantom (Golizadeh, Hosseini, Edwards, *et al.*, 2019a). Consequently, UAVs have been classified into aircrafts used for research purposes, government objectives or commercial applications and model aircrafts used for leisure or recreation. Within the decade, drones have gained relevancy within the construction and engineering industry (Sanson, 2019). Their uses within the industry encompass multiple practical aspects of construction such as construction surveying, construction inspections, construction safety, and 3D modelling (Anwar, Izhar and Najam, 2018; Harinarain and Naicker, 2019; Mahajan, 2021).

Furthermore, the implementation of drones within the construction sphere is rapidly developing in practical applications during the execution stage of construction projects

(Howard, Murashov and Branche, 2018; Zhou, Liu and Ren, 2020; Albeaino and Gheisari, 2021; Rodríguez *et al.*, 2021). According to Grosso *et al.*, (2020); Shariq and Hughes, (2020); Nooralishahi *et al.*, (2021) the application of UAVs for non-destructive monitoring and inspections of construction sites is growing due to their reliability and effectiveness when compared to traditional approaches. Other researchers such as Patrick, Nnadi and Ajaelu, (2020) and Petrova, Mostovoy and Zaripova, (2021) affirm this notion stating that drones allow the project team more real-time and detailed control over the project during execution. In addition, features such as long range, speed, area photogrammetry capabilities and efficient data capture address human limitations inherent on performance during inspections.

In spite of this, drone technology application in the construction industry is still lacking in most countries including South Africa (Mohsan *et al.*, 2022). This is despite the market availability of drones and known capabilities. Alsamarraiea *et al.*, (2022) states that despite the vast capabilities to support construction needs and practices over traditional practices relating to quality of inspections, drone technology still faces obstacles impeding its full adoption. More so, Elghaish *et al.*, (2021) note that the use of UAVs for construction site inspections seem to be lacking due to perceived technical, managerial, and regulatory challenges.

Furthermore, studies such as Fan and Saadeghvaziri, (2019) and Patrick, Nnadi and Ajaelu, (2020) contextualized within developing countries highlight some challenges hindering full adoption and use of drones on construction sites. On the other hand, Jeelani and Gheisari, (2021) discusses safety challenges relating to the integration of UAVs in construction execution activities. Hence, it has been noted that these challenges discourage contractors from actively engaging in drone technology deployment strategies to enhance construction management performance (Alaloul *et al.*, 2018; Devers, 2019; Golizadeh, Hosseini, Edwards, *et al.*, 2019a; Charlesraj and Rakshith, 2020; Sawant *et al.*, 2021; Mohsan *et al.*, 2022)

South Africa is a developing country focused on major infrastructure development such as the NDP, 2030 (National Development Plan). Moreover, the country has a well-established drone technology platform (Ikuabe *et al.*, 2020). However, despite the availability and access of drone technology, the deployment and application of these devices within construction has not reached full potential (Delgado *et al.*, 2019; Harinarain and Naicker, 2019; Aiyetan and Das, 2022). The country is in a state where construction industry professionals are aware of drones but unaware of drone technology use in construction. According to Harinarain and Naicker, (2019) 70% of industry professionals perceive drone technology as a tool that would greatly assist the industry on efficiency in areas such as construction site inspections and progress monitoring.

On the other hand, Ikuabe et al., (2020) ranked drone technology the 3rd most involved digital technology within the South African construction industry following IoT and sensors. However, the rapidly growing complexity and scale of construction projects in South Africa, driven in part by the NDP2030, reflects suboptimal deployment of drones given their performance aiding capabilities in areas such as site inspections and monitoring (Aghimien *et al.*, 2019; Delgado *et al.*, 2019; Osunsanmi *et al.*, 2020).

1.2. Background to the research problem

Complexity means coordinating a large number of project team members, goods, and equipment which can expose contractors to a variety of risks (Mathern and Magnusson, 2022). The increasing complexity and scale of construction projects necessitates identification of solutions that will enhance productivity and transform project delivery (Enegbuma *et al.*, 2016; Goger and Bisenberger, 2020). Therefore, regular construction site inspections are important to successfully manage a construction site over the entirety of the project's life cycle. Furthermore, inspections contribute to ensuring the effectiveness and security of both the building process and the end product (Lu *et al.*, 2022a; Suleiman, 2022). Early defect detection through prompt inspections enables defects to be resolved before continuing with the next tasks. As such, inspections aid teams in avoiding redoing work and the associated expenses and delays. However, there are limitations with existing inspection practices (Falorca and Lanzinha, 2020; Rey, de Melo and Costa, 2021; Lee, Nie and Han, 2022; Halder *et al.*, 2023)

Traditionally, inspectors have had to traverse entire construction sites on foot in order to inspect on-site practices or works being performed. Often, complex construction projects with challenging site layouts sometimes have poor on-foot inspections and subsequent documentation (Zulkifli *et al.*, 2018; Kazaz *et al.*, 2021). Additionally, the conventional methods of accessing rooftops, high walls, and other difficult-to-reach areas of buildings is one of the main limitations with building inspections (Falorca and Lanzinha, 2020). Rope access and scaffolding are two risky, expensive, and time-consuming options which might make it more difficult to see and collect specific information about particular construction components.

However, unmanned arial vehicles are challenging these traditional inspection practices (Falorca, Miraldes and Lanzinha, 2021a; Al Zaabi *et al.*, 2022; Halder *et al.*, 2023). As a safe and affordable option for building inspections, drones are increasingly used for a variety of commercial and professional purposes (Nooralishahi *et al.*, 2021; Guan, Zhu and Wang, 2022; Nordin *et al.*, 2022). Consequently, the hazards and expensive expenses involved with manual or traditional building inspections are eliminated by drone-based inspections. In addition to saving money, drones can access practically all surfaces with ease, take in-depth pictures, videos, and thermal images, and enable inspectors to conduct inspections safely without the need to send personnel up a ladder or pay for access equipment.

1.3. Articulation of the research Problem

As projects become more complex and larger in scale, the limitations of CSM become more apparent (Adebowale and Smallwood, 2020). Numerous studies have explored the challenges associated with manually managing on-site activities. These involve lack of coordination of on-site activities (Ozumba and Shakantu, 2017; Ozumba *et al.*, 2019), improved processes and strategic technology adoption (Enegbuma *et al.*, 2016), poor CSM as a result of the lack of technology adoption (Ozumba and Shakantu, 2020).

Furthermore, the construction industry in those countries such as South Africa that are developing countries often relies on manual processes. As a result, project monitoring primarily involves documenting data that is not immediately analysed, which can lead to delays in detecting scope and budget deviations (Safa and Hill, 2019). The lack of early recognition hinders the prompt adoption of necessary actions, leading to significant financial and reputational repercussions (Schuh *et al.*, 2017; Batarseh, 2018). In order to enhance efficiency, control, and overall project performance, it is essential to adopt technological solutions that enable the real-time capture and processing of data related to execution processes for informed decision-making in project monitoring and quality control. (Martinez-Rojas *et al.*, 2018; Ram, Afridi and Khan, 2019; Martínez-Caro, Cegarra-Navarro and Alfonso-Ruiz, 2020)

Grosso *et al.*, (2020) performed an analysis of drone technology deployment for construction inspections and progress monitoring during the execution stage of construction projects. From their findings, they conclude that drone technology has utilities that can enhance site management processes and achieve efficiency including high-quality inspections and monitoring. Furthermore, Jordan *et al.*, (2018) indicates that the lengthy and labour-intensive inspections with subjective qualities as well as the requirement of special inspection tools would be eliminated by the deployment of UAVs on construction sites. Although there is scarcity of literature on the use of UAVs in construction site management in South Africa, available literature alludes to some level of poor adoption for inspections of construction works to maintain quality during contract administration.

From the above-mentioned, it can be argued that there is a need to identify and classify the particular challenges that would go against the adoption of drone technology during contract execution, especially stage 5 as per SACPCMP scope of works guidelines (SACPCMP, 2019). Specifically, when being deployed for construction site inspections as an area of construction site management. Furthermore, there is a gap in knowledge about the nature and occurrence of challenges behind the poor adoption of drone technology for inspections during construction execution in the context of South Africa. Therefore, there is a need to move forward and explore what these challenges are and possibly how they can be addressed. Appreciable research has been done globally on the benefits of drone technology adoption for construction site management performance enhancement (Fan and Saadeghvaziri, 2019; Greenwood, Lynch and Zekkos, 2019; Rachmawati and Kim, 2022).

Notably, the application of drones for monitoring progress of construction works, underlining improvement capabilities from conventional inspection methods (York, Al-Bayati and Al-Shabbani, 2020). However, not much research has been done in exploring challenges (from the perception of key role players) that lead to poor deployment of drone technology on construction sites for drone-aided inspections (Ikuabe *et al.*, 2020; Nkamisa, Abrahams and Thukani, 2021; Aiyetan and Das, 2022). Therefore, this research provides insights on the hinderances causing low level of drone technology utilisation for construction project inspections, in order to provide information that can be used to address poor adoption.

1.4. Problem Statement

The application of drone technology has been realised within the South African construction industry. However, there is poor adoption of drone technology for proliferation of drone-aided construction site inspections during the execution stages of construction projects.

1.5. Research Question

The research question is as follows:
What are the challenges hindering the deployment of drones on construction sites for drone-aided inspections by key role players during construction project execution?

1.6. Research Sub-questions

The main research question was broken down into the following sub-questions in order to be answered systematically.

1. What is the diffusion of commercial drones for construction related applications within the South African construction industry?
2. What is the nature and occurrence of challenges to drone technology deployment for drone-aided inspections during construction execution stage of projects in South Africa?
3. How can identified challenges impeding optimal utilisation of drones during the execution stage of construction projects be addressed?

1.7. Research Aim

The aim of this research is:

To assess the challenges hindering the deployment of drones on construction sites for drone-aided inspections by key role players during construction project execution.

1.8. Research objectives

The following objectives are derived from the research aim:

1. To ascertain the diffusion of commercial drones for construction related applications within the South African construction industry.
2. To determine the nature and occurrence of challenges to drone technology deployment for drone-aided inspections during construction execution stage of projects in South Africa.
3. To suggest ways of addressing identified challenges impeding optimal utilisation of drones during the execution stage of construction projects.

1.9. Research premise

The premise of this research is that there are specific challenges that hinder the deployment and optimal use of drones for inspections during construction project execution. It posits that these challenges exist within the South African construction industry and that understanding and addressing them will enhance drone utilisation in construction projects. The research is framed on the idea that despite the potential benefits, hinderances to drone adoption in construction need to be identified and overcome for better integration into industry practices.

1.10. Statement of the research design

Achieving the above stated objectives required a systematic formulation of a research design that encompass methodical and methodological aspects relevant to the study. In this context, the research design outlined a systematic and strategic approach that guided the researcher in making sense of the subjective and socially constructed meanings relating to the challenges impeding drone-aided inspections proliferation and to better understand their nature and occurrence. Ultimately, drawing meaningful conclusions.

That being said, the interpretivist philosophy was the paradigm that guided this research, driven by the exploratory nature of the study and the inductive approach to theory development. Furthermore, a multi-method qualitative methodology was adopted with document analysis and case study employed as the research strategies. Document analysis, being an archival/documentary research strategy, was used to ascertain the diffusion of commercial drones for construction related applications within the South African construction industry. The case study strategy was applied for empirical data collection using contextual inquiry and interviews as techniques of data collection. Data collection instruments were designed in the form of semi-structured interviews, non-participant observation and focus groups. The data collected was analysed using content analysis and thematic analysis techniques with NVivo software used as the data analysis tool.

1.11. Research scope

The main subject of the study is the exploration of challenges facing deployment of drone technology to enhance quality in construction site inspections. The main topics are digital and automation technologies in construction, construction site management and innovative project management, with a particular focus on drone-aided inspections of construction works during the execution stage of construction projects (stage 5 as per SACPCMP guideline). The type of inspection that the research will focus on is quality control inspections. These inspections involve routine site walkthroughs to make sure that the materials used, and the work completed complies with all relevant regulations as well as the specifications and standards outlined in the contract agreements (Lin et al., 2020).

The subdivision of drone technology that will be explored is photogrammetry. In simple terms, drone photogrammetry is the process of accurately creating three-dimensional topographical models and orthomosaic maps using a large number of two-dimensional photos taken from a drone over a certain location (Lee et al., 2022). Thus, this study will focus on the challenges to the implementation of drone technology on a construction site utilising photogrammetry in carrying out a quality control inspection on the façade of the building being built. The target population for the study will include construction project managers, construction site managers, construction inspections specialists, drone experts and clients' project managers. This study is a cross-sectional study that will be carried out in South Africa within Gauteng Province for the duration of the researcher's master's degree programme.

1.12. Research assumptions

This research is based on the assumption that the South African construction industry is moving through a progressive transition that includes the adoption of drone technology to enhance CSM processes. Therefore, the researcher assumes that:

- Construction project professionals will always encounter challenges in deploying drones for drone-based inspections.
- The factors influencing poor adoption of drone technology can be revealed through perceptions of key role players.
- Factors impacting the level of drone technology utilisation on construction sites can be revealed through contextual injury.

With regards to data collection, the following assumptions were made in this study:

- Respondents will answer questions honestly and candidly.
- Inclusion criteria of sample will be appropriate.
- Participation will be sincere, without hidden motives.

1.13. Research Limitations

The research aim & research question refers to assessing the challenges to drone-aided inspections in South Africa. However, the study was confined to Gauteng, which may not fully represent the entire South African construction industry.

As such, the study had several limitations:

- Data obtained through contextual inquiry was from public works cases only, not privately owned sites.
- Lack of access to variety of drones as only one drone was used across the three cases.
- This research, being undertaken for an academic course, was time constrained.

Moreover, it is a study of a particular phenomenon – exploration of challenges to drone technology proliferation for enhanced site inspections – at a particular time. Hence, it is a cross-sectional study (a 'snapshot' of a phenomenon at a particular time) that employs only qualitative research strategies conducted over a short period of time.

1.14. Rationale for the Study

Although the construction industry is known to evolve at a slow pace, the need for greater efficiency and quality control has necessitated exponential growth in drone technology application (Nordin *et al.*, 2022). Therefore, there is a need to explore hindrances to the use of this technology that is set to impact project bottom line in the near future and over time. Moreover, responsivity of the industry culminating from industry needs requires support from academia (Williamson and Gage, 2019). According to Golizadeh, Hosseini, Martek, *et al.*, (2019) growth in practical applications of drone technology within the construction industry also rely on academic discourse addressing factors hindering widespread adoption.

Furthermore, the adoption of drone technology for construction related applications is expected to initiate research exploring implications and possibilities of deploying drones to redefine conventional practices (York, Al-Bayati and Al-Shabbani, 2020). UAVs have already started to impact operational practices in construction contract administration and the prospects are promising given the development towards integration with other systems such as IoT, GIS, and BIM. Consequently, understanding the level of drone technology deployment within the South African construction industry and the influencing factors in its adoption is an interest of the author.

1.15. Contribution to body of knowledge

The envisaged contribution of this research is twofold. The researcher envisages contribution to both academic discourse and the South African construction industry. Within the academic discourse, the researcher aims to advance articulation of drone technology application within CSM for enhanced and efficient inspections of construction works. Thus, outlining the nature and influence of challenges to drone technology deployment within CSM. Optimistically, the result will inform future research on real-time drone-based inspections actualisation during construction execution within the context of South Africa. Through the comprehensive exploration of this study on the challenges of drone-aided inspections of construction site works in South Africa, the influence of these challenges on the level of adoption will be revealed, emphasised, and scrutinised (Flynn and Kramer, 2019).

Furthermore, this research will elucidate the nature and occurrence of challenges hindering increased adoption of drone technology for construction site inspections. This will highlight the prevalence of such challenges within the local construction industry scenario. In this regard, the study will create awareness to key construction industry professionals on how these challenges affect the level of utilisation of drones for enhanced and efficient inspections of construction works (Mohajan, 2018). Moreover, through the analysis that will be made in this research, construction industry professionals, entities and institutions can learn the influence of these challenges on their willingness to adopt and implement drone technology. Thus, they will be able to derive strategic approaches to addressing these challenges.

In addition to this, the overview presented in this research will create an exploratory platform to the challenges leading to poor utilisation of UAVs for construction site inspections. This new paradigm will be useful for discourse on leveraging drone technology as a tool for process enhancement during the construction execution phase of projects (Nowell and Albrecht, 2019). This will foster future discussions linking the potential utility of drone technology to shortcomings in the deployment process of UAVs in construction site management. Furthermore, this study will provide academia with a baseline understanding of the relevancy of challenges hindering the full potential of UAVs applications within site management. Therefore, advancing knowledge on the need to address the challenges to the use of drones in site management to address areas of weaknesses in the CSM process.

Consequently, a detailed presentation on the analysis and categorisation of challenges explored in this research may serve as a basis for future studies seeking to examine the deterrence level of these challenges on UAVs adoption by local construction industry professionals (Flynn and Kramer, 2019; Knight, 2021).

1.16. Chapters overview

This dissertation is structured according to the following chapters:

Chapter 1: Conceptualising the research

The chapter introduced drone technology adoption within construction site management for drone-based inspections of construction works as the subject matter of this study. As such, the background on the uses and applications of drone technology was outlined. Moreover, the lack of adoption of the technology within the South African construction industry context was substantiated.

Previous research on the topic was used to draw a brief attention on the challenges fostering lack of adoption. This was done to derive the problem statement of the research and consequently, the primary research question and research aim. Furthermore, from the aim, four research objectives which guided this research were identified. Additionally, the scope of the research was laid out while having described the research premise and certain assumptions that were made in the study. Finally, limitations out the researcher's control that impacted or influenced the way in which this research is applied and interpreted were made. In closing, the rationale for this study and envisaged significance of the research study were elaborated.

Chapter 2: Literature review

In this chapter, findings derived from the literature review regarding construction inspections and the application of drone technology in construction processes are presented. The chapter begins by detailing the role inspection practices play in construction site management and how these practices have evolved over time owing to their importance. Relevant literature is presented on construction site inspection challenges and how drone technology can be utilized to potentially overcome these challenges, not forgoing drone related challenges. Lastly, a theoretical framework is presented based on key knowledge areas and theories relevant to the research in order to introduce the conceptual framework that guides the study.

Chapter 3: Research methodology

This chapter discusses the appropriate methodological and methodical framework employed in order to coherently and logically integrate the overall aspects of the research. Thus, the chapter articulates a systematic approach for answering the research question, how the data collection and analysis procedures were approached in order to represent the findings more effectively.

Chapter 4: Presentation of data findings and analysis

This chapter presents the findings from the document analysis, the case studies, and the interviews relating to objectives 1,2 and 3 respectively. Data from the review of documents, semi-structured interviews with participants in the case studies, and interviews with drone industry professionals and construction industry professionals is analysed and presented in this chapter.

Chapter 5: Discussion of results

This chapter discusses the findings and analysis based on the empirical data collection process in relation to the findings from the review of extant literature making reference to the DOI-TOE framework.

Chapter 6: Conclusions and recommendations

This chapter concludes the dissertation, explains the contribution of the research to the construction industry and academia, providing pertinent recommendations and suggestions for future research.

The figure below graphically illustrates the structural flow of the dissertation.

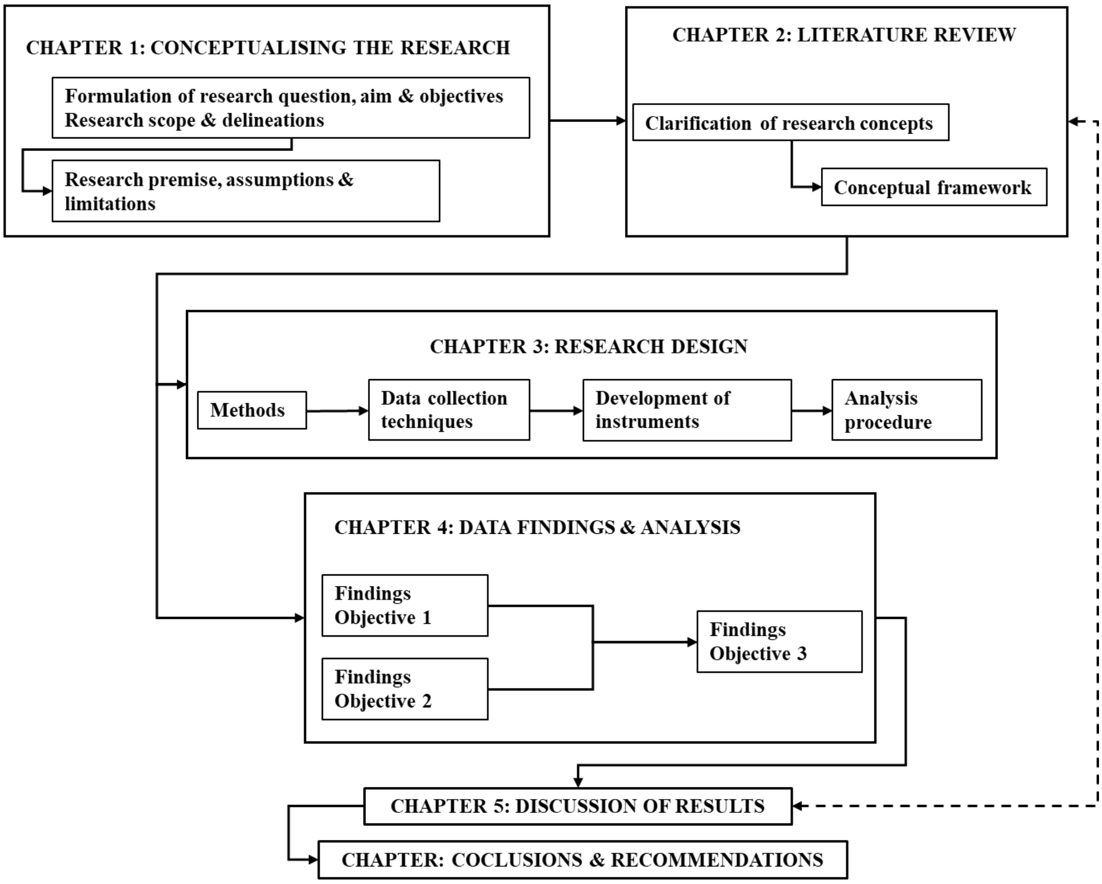

Figure 1.1: Structural logic of dissertation

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

Before the aim of the study can be empirically achieved; it is a necessity for academic research to explore relevant literature on the topic. Therefore, the following chapter provides an in-depth understanding of the research aim and concepts through an integrative review of literature. The objectives of the literature review are as follows:

1. To ascertain the current state of inspection practices and the role they play in construction project management.
2. To determine the current state of knowledge in drone technology and drone-aided inspections in construction project management.

Thus, this chapter uncovers the body of knowledge pertaining to key knowledge areas of the research by critically reviewing existing literature concerning the research problem. A constructive critical review of journal articles, conference proceedings and online papers obtained from different sources was carried out to gain in-depth understanding and knowledge related to the main research question. These relate to construction site management, drone technology adoption and drone-aided inspections within construction project management. Thus, the purpose of this literature review is to detail the role inspection practices play in construction site management and how these practices have evolved over time owing to their importance.

Moreover, this chapter explains construction site inspection challenges and how drone technology can be utilised to potentially overcome these challenges. The literature review also explicates drone technology, its application in construction project management and how drone-aided inspections compare to conventional inspection methods. Firstly, the chapter discusses inspection practices in construction project management, elaborating on its evolution and the types of inspections generally carried out on construction sites. Thereafter, quality inspections are presented as a specific area of inspections which the study focuses on in laying a foundation for drone-aided inspections on construction sites which is subsequent. Lastly, a theoretical framework is presented based on key knowledge areas and theories relevant to the research in order to introduce the conceptual framework that guides the research.

2.2. Inspection practices in construction project management

2.2.1. The role of construction site inspections

In construction project management, it is mandatory to identify the impact of key factors associated with adverse outcomes on construction projects so that appropriate solutions or alternatives can be employed (Djaelani *et al.*, 2021). Moreover, construction projects involve the coordination of key stakeholders, resources and materials which are factors in process problems exposing contractors to a myriad of risks and potential hazards (Al Zaabi *et al.*, 2022). Therefore, to guarantee that works are going according to plan, standards and regulations, in terms of quality and compliance, routine inspection strategies are implemented as an intrinsic part of the project management plan (Nena, Musonda and Okoro, 2021).

As such, routine inspections are performed throughout the life cycle of the project apart from contractor's supervision of the works, for multiple purposes in accordance with the plans and specifications (Laryea, 2019; Al Zaabi *et al.*, 2022). Moreover, construction inspections are generally performed as a contractual obligation to enable an independent view of construction works and their progress for key stakeholders and the client (Zulkifli *et al.*, 2018; Mathern and Magnusson, 2022).

On that account, inspection of works on construction sites are guided by project specifications and construction industry standards so as to analyse project conformance. On-site inspections are necessary as they allow construction professionals to recognize risks and potential issues and record them for corrective action to minimize their effect on the triple constraints of project management (Nielsen, 2017; Hussamadin, Jansson and Mukkavaara, 2023).

Hence, construction site inspections are critical activities that ensure industrious production, worker safety and quality control (Lin *et al.*, 2020; Lu *et al.*, 2022a). They enable the documentation of construction site conditions and the discovery of deficiencies to ensure all site activates follow appropriate standards and contract requirements. They are purposeful in identifying potential health and safety hazards (Rey, de Melo and Costa, 2021), preventing safety violations (Rey, de Melo and Costa, 2021; Suleiman, 2022), documenting quality issues and deviation from standards (Mathern and Magnusson, 2022), as well as aiding insurance claims (Lin and Fan, 2018).

Thus, the role of construction site inspections is to make sure that quality standards and safety protocols are being followed effectively for the successful management of the construction site throughout the project. Furthermore, inspections promote greener construction as they foster compliance to specific environmental regulations and the use of sustainable construction materials and practices (Li *et al.*, 2019). In addition, they ensure conformance to applicable building codes, thus guaranteeing structural integrity, safety of workers and the occupants (Lu *et al.*, 2022a).

2.2.2. Construction site inspection types: who does them, how and why

Due to the dynamic nature of construction projects, active action to and assessment of on-site problems is crucial for effective efficient construction management and decision-making (Suleiman, 2022). Thus, in the pursuit of delivering hazard-free and quality projects, certain construction site inspection types have been derived from the requirements that construction specifications and regulations impose on construction projects (Ding *et al.*, 2017; Mohamed and Tran, 2022; Suleiman, 2022). As such, routine inspections are carried out for multiple purposes throughout the project life cycle to analyse project progress and ensure the contractor is proceeding continuously, industriously, and efficiently (Al Zaabi *et al.*, 2022; Laryea, 2019).

However, most inspections are performed during the construction execution phase of construction projects as part of the contract signing, contract review and the onboarding of clients (Pal *et al.*, 2023). Construction site inspections are usually performed by the project manager, specific project team members, or an external inspector dependent on the scale and complexity of the project (Zulkifli *et al.*, 2018). When an inspection has been performed, the contractor receives an inspection report that acts as evidence proving the inspector conducted proper tests to uphold the quality of the infrastructure (Lu *et al.*, 2022a; Mathern and Magnusson, 2022; Suleiman, 2022).

Essentially, measures of inspections include quality control, health, & safety, building control and environmental assessment among others. Table 2.1 below highlights basic inspection processes conducted on construction sites. The table shows internal safety, health, environmental and quality (SHEQ) inspections, the types of inspection audits and certain plant and machinery inspections performed on construction sites in accordance with project specifications and applicable regulations.

Table 2.1: Inspection process frequency, roles, and responsibilities

Inspections	Frequency	Participants	Record
Internal SHEQ inspections	As determined by audit schedule	SHEQ Manager, SHEQ Officer, Responsible Manager	Inspection reports
External Audit/ Inspections	As determined by the applicable body	Dept of Labour; Client Agent; Dekra Auditors; etc.	Inspection reports/Audit, Noncompliance
Quality of work	As identified in applicable SHEQ procedure & SHEQ / Inspection plans	Supervisors Subcontractors Relevant engineers	Applicable quality checklist. Test certificates Completion lists
Legal compliance audit	Ongoing	SHEQ Manager, external expert Relevant manager	Legal compliance audit report
Subcontractor audit	As identified in the Construction regulation	Safety officer; subcontractor representative	Audit report
Site tools & equipment	As determined by applicable regulation, client H&S spec, H&S plan, risk assessment	Appointed person Subcontractors to provide proof of compliance	Applicable checklists
Plant Yard tools & equipment	As determined by applicable regulation	Appointed person	Applicable checklists
Lifting Machinery	As determined by applicable regulation (OHS Act Driven Machinery Regulation 18)	Plant manager to ensure inspections are planned & conducted. Lifting & machinery inspector to conduct load testing. Operator to complete daily checklist.	Load test certificate Daily checklist
Lifting Tackle	3 monthly inspections. As required by clients H&S specification	External approved testing authority	Load test certificate, Inspection report
Pressure Vessels	3 years or as identified	External approved testing authority	Test report

Accordingly, on-site inspection enables regular monitoring, auditing, and reporting of the construction processes to ensure that the finished project satisfies all requirements at any point during the development process (Lin *et al.*, 2020). Hence, there are various types of site inspections that are crucial for ensuring the safety, quality, and compliance of construction projects. According to (Lin and Fan, (2018) and Mohamed and Tran, (2022) each inspection process serves a specific purpose in monitoring and maintaining the integrity of the project and involves different stakeholders. Understanding these processes, which are primarily vision-based, and what they entail is paramount for successful project management and contract execution. Therefore, these types of inspections are discussed next.

Progress inspections

Progress inspections are a fundamental aspect of construction site management in that they are key in ensuring timely and successful completion of construction projects (Jacob-Loyola *et al.*, 2021). Progress inspections are largely concerned with tracking project timeline and milestones to ensure that progression is according to the predetermined schedule. These inspections involve the regular assessment of construction progress, the verification of adherence to project schedules and milestones, and the identification of any potential delays or issues that may impact the project timeline (Alaloul *et al.*, 2021; Reja, Varghese and Ha, 2022). Therefore, inspectors assess the completion of predefined tasks, the achievement of project milestones, and any deviations from the initial timeline. Mahami *et al.*, (2019) and Alaloul *et al.*, (2021) explain that this process facilitates effective project management through the identification of inefficiencies, thus allowing corrective measures to proactively address challenges and implement necessary adjustments.

Consequently, timely interventions, such as revising work schedules, reallocating resources, or implementing alternative construction methods minimize delays and keep the project within the set timeline and budget (Greeshma and Edayadiyil, 2022; Pal *et al.*, 2023). Ultimately, progress inspections are essential checkpoints during construction progression to ensure that the project stays on schedule. Progress inspections can be conducted by project managers, architects, engineers, or appointed consultants (Mahami *et al.*, 2019).

Daily site inspections

Daily site inspections provide construction site managers with a systematic approach to constantly monitor and maintain the progress, safety, and quality of work done (Nielsen, 2017). According to (Sherafat *et al.*, 2020) daily site inspections entail a day-today thorough inspection of the site which enables the construction management team to identify potential hazards and violations and ensure continuous compliance with safety regulations. Furthermore, Pal and Hsieh, (2021) note that this process involves the daily assessment of construction activities and work conditions.

Hence, the purpose of daily inspections is to ensure that work done the previous day is satisfactory as well as making sure that the work planned for the day is on schedule (Pal and Hsieh, 2021). A general walkthrough of the construction site is undertaken by the supervisor, safety manager, site manager or site engineer to assess the personnel on site, the work completed and the status update on the work in progress (Sherafat *et al.*, 2020). Intrinsically, inspectors assess the status of ongoing tasks, review the achievement of daily goals, and track the overall project timeline to ensure that resources are allocated accordingly, and construction progression is industrious.

Similarly, daily site inspections prioritise the evaluation of safety measures and hazard assessments to ensure continuous compliance to safety protocols (Rolfsen and Lassen, 2020). Inspectors identify potential safety risks, conduct equipment checks, and assess the implementation of safety procedures to prevent accidents, injuries, and health hazards for workers and the public. According to Fang *et al.*, (2020), daily site inspections serve as a proactive mechanism for construction site management, enabling managers and supervisors to maintain a safe, efficient, and productive construction environment. Through comprehensive documentation and reporting, inspectors maintain detailed records of daily activities, inspection findings, and any corrective actions taken. Conventionally, tools such as PDAs, clipboards and checklists are used and the results obtained are utilized to mitigate schedule delays, improving productivity as well as preventing accidents and injuries (Fang *et al.*, 2020; Rao *et al.*, 2022).

Health & safety (H&S) inspections

On the other hand, health and safety inspections entail a site walkthrough process where the inspector reviews each element of the site rigorously with the intent to identify hazards that might threaten the health and safety of any worker, contractor, or visitor (Djaelani *et al.*, 2021; Martinez *et al.*, 2021; Suleiman, 2022). In other words, health and safety inspections are a systematic evaluation of the construction site, equipment, and processes to identify potential hazards, assess risk levels, and foster regulatory compliance with health and safety standards. Consequently, H&S inspectors assess the safety policies in place and detects any potential hazards on site such as hazardous material exposure, safe work equipment, and any other potential dangers (Olanrewaju, Khor and Preece, 2021).

Traditionally, inspections are performed visually with paper-based checklists or smart applications to ensure protective measures are in place (Martinez *et al.*, 2021; Tekin, 2022). According to Olanrewaju *et al.*, (2021), construction H&S inspections might focus on particular areas such as work-at-height control measures or adopt a more comprehensive approach and inspect every aspect of the construction site. Hence, they provide practical tools to increase compliance to local, national, and industry-specific construction regulations and safety standards.

Evidently, health and safety inspections are crucial in that they help identify potential hazards and ensuring safety measures used for protecting people and property are in accordance with occupational safety and health administration (OSHA) standards (Tekin, 2022). A competent person according to OSHA definition, a qualified person according to OSHA standards or a dedicated safety professional uses visual observations to assess physical hazards, workplace hazards and unsafe working conditions. Using inspection logs, H&S checklist and visual aids, they are able to promptly identify risks and correct them before accidents happen, thus achieving a proactive prevention of work-related injuries (Martinez *et al.*, 2021; Rey, de Melo and Costa, 2021).

Furthermore, the identification and communication of unavoidable risk zones enable the planning and development of accident mitigation strategies and prevention actions

(Ma, Chong and Liao, 2020). In this regard, promptly recognising and fixing these errors guarantees worker safety and work continuity. Therefore, contractors are required to follow OSHA regulations and guarantee that the site complies with all necessary health and safety requirements (Nielsen, 2017). In essence, H&S inspections play a crucial role in preventing incidents, illnesses, and injuries brought on by work-related hazards that may be avoided. However, the effectiveness of these H&S inspections is dependent on the experience of the inspector in charge (Halder *et al.*, 2023).

Quality control inspections

The PMBOK defines quality control as the practice of keeping track of and documenting the outcomes of carrying out quality-related tasks in order to evaluate performance and suggest required adjustments (PMI, 2021). The two main advantages of this process are: (1) determining the primary causes of substandard process or product quality and suggesting and/or implementing corrective action to address them; and (2) verifying that project deliverables and work satisfy requirements required for final approval as stipulated by key stakeholders (Ding *et al.*, 2017; PMI, 2021). Hence, quality inspections are conducted to assess the workmanship, materials used and overall construction processes to ensure they meet the required quality standards and project specifications. Likewise, technical specifications that describe controls to be carried out guarantee satisfaction of works (Hajdukiewicz *et al.*, 2019).

Consequently, this type of inspection aims to identify any deviations or defects that could compromise the delivery of a quality product. The focus of quality control inspections encompasses the structural integrity of components, precision of installations and adherence to design plans to verify quality and suitability of the as-built structure as construction progresses (Ma, Chong and Liao, 2020; Mathern and Magnusson, 2022; Ribah and Singh, 2023). During the inspection process, a quality control manager, engineer or third-party inspector assesses the finished work in terms of compliance with industry standards and project specifications. Hence, functional tests, load tests, and system checks are conducted to verify that these components operate efficiently, meet performance requirements, and comply with safety regulations and industry standards (Hajdukiewicz *et al.*, 2019; London, Pablo and Gu, 2021; Ribah and Singh, 2023).

In an integrated delivery project approach, quality control inspections may involve incorporating client feedback and satisfaction assessments to make sure that client expectations are met or exceeded (Ma, Chong and Liao, 2020). In essence, inspectors actively work collaboratively with construction teams to integrate client preferences into the quality control processes. Moreover, they provide recommendations regarding the implementation of quality management systems and foster a proactive approach to prevent quality deviations (Ali, Mubin and Gavrishyk, 2022; Parsamehr *et al.*, 2023). As such, comprehensive documentation and record-keeping are integral. Accordingly, detailed records of inspection findings are affirmed for corrective actions, and quality assurance procedures.

An inspection plan is also aligned with the quality control plan for preventative measures in the case where construction project managers require assurances of construction quality (Parsamehr *et al*, 2023). Hence, the documentation, work instructions, action plans, and other items used in the execution and management of construction activities are also subject to inspections. Furthermore, it is also possible for third-party certificates to take the role of these quality control inspections (Mohamed and Tran, 2022).

Building regulation Inspections

In contrast to quality inspections, building control inspections are performed to ensure adherence to the building regulations and standards meant to safeguard occupant welfare, health, and safety within and around built environments (Murtagh, Achkar and Roberts, 2016). This covers brand-new structures as well as renovations, additions, and installations. Typically, a full plans application will be filed for larger, new-build projects, ensuring that complete details of the proposed construction works are submitted for approval before the works are carried out (Comiskey *et al.*, 2018; Bortolini and Forcada, 2020).

However, building notices can be used to request approval for small projects or when modifying an existing structure. In this situation, a building inspector will approve the work as it is being done through an inspection process in accordance with SANS 10400-A. This SABS standard provides comprehensive guidelines for meeting the National Building Regulations, which are issued under the National Building Regulations and Building Standards Act, 1977 (Act No. 103 of 1977) (Malomane, Musonda and Okoro, 2022). This type of inspection can be carried out by an approved independent inspector or a building control inspector from the municipal authorities (Murtagh, Achkar and Roberts, 2016; Nena, Musonda and Okoro, 2021). Traditionally, only municipal authorities could perform this inspection; however, it is now also possible for privately contracted, registered inspectors to perform this function.

Furthermore, a satisfactory building inspection is not a guarantee of quality labour, appropriate paint selections, or other factors. A successful building inspection does, however, imply that the structure meets requirements for occupant safety (Shariq and Hughes, 2020). Moreover, it verifies if the building was constructed in accordance with the approved structural requirements and acts as evidence that all work was authorized by a permit and adhered to minimal safety standards (Murtagh, Achkar and Roberts, 2016; Hussamadin, Jansson and Mukkavaara, 2023).

To that effect, the building control inspector will examine the completed work, assess its compliance with authorized plans or the building code (if applicable), and produce an inspection report during the inspection. The report will either indicate if the inspection was successful or give a list of corrections that must be made before a subsequent inspection (Bortolini and Forcada, 2020; Dias, Flores-Colen and Silva, 2021). As is evident with other types of inspections, this inspection process is also carried out manually where visual walkthroughs are performed.

Environmental inspections

According to Nyamazana, (2019), the environmental impact caused by substantial disruptions to the local environment due to project complexities, plant and the equipment involved on construction sites can potentially surpass all other stages of the project lifecycle. Evidently, construction activities contribute significantly to environmental impacts such as destruction of natural habitats, consumption of natural resources, carbon emissions, generation of waste, and energy consumption. Air pollution, noise pollutions and the release of toxic gases on site adversely impact the project environment and surrounding (Sudevan, Shukla and Karki, 2018). Hence, site specific environmental impact assessment (EIA) is employed in line with the environmental management plan.

EIA underscored by inspections involve air quality monitoring, noise monitoring, waste management and water quality monitoring in order to identify environmental issues to existing environmental requirements (Nyamazana, 2019; Falorca and Lanzinha, 2020). Third-party environmental inspectors, specialists or officers evaluate the environmental management plans, environmental impact assessment criteria and the overall environmental conduct of the construction site to gauge compliance to environmental regulations. Accordingly, environmental monitoring of construction site activities is underpinned by recognized environmental management standards such as ISO14001 (Hajdukiewicz *et al,* 2019). Consequently, environmental inspections are essential to mitigate the impact of construction activities on the environment, prevent pollution, and ensure sustainable construction practices.

Specialised inspections

Specialised inspections encompass mechanical, electrical and plumbing (MEP), HVAC, and fire safety inspections. They are detailed assessments conducted by qualified professionals who specialize in specific areas of construction (Al *Zaabi et al*, 2022). These inspections entail thorough evaluations of specific elements, systems, or components of a construction site to ensure compliance with industry standards, safety regulations, and design specifications. Various specialised inspections may be conducted during different phases of construction to identify any potential issues, ensure the quality of work, and verify that construction practices meet the required criteria (Jawad, Anikesh and Gayathri, 2021; Cai, Huang and Zou, 2023).

Draw inspections

These are the simplest of construction site inspections. They are carried out by a third party on the project financier's behalf to confirm progress and milestones before additional payment ca be made (Heitz, Martin and Ufier, 2022). Visual walkthroughs are employed to compare the reported progress against actual progress to verify if work completed matches the draw. In essence, draw inspections are essential for mitigating the financial risk associated with construction loans and gives the financier guarantee that construction is proceeding as intended (Xu *et al.*, 2019).

Generally, conventional inspection methods are usually inefficient with high risks involved from inspections of high-rise or complex structures (Lin *et al.*, 2020; Tan *et al.*, 2021). Lin *et al,* (2020) argue that paper-based files such as data collection forms and checklists conventionally used for on-site inspections are insufficient for real-time information exchange and communication. Similarly, Al Zaabi *et al*., (2022) notes that managers end up spending approximately 30% to 50% of their time recording and analysing site data due to the manual nature of construction inspections. Furthermore, manual inspection procedures are dependent on the availability of inspectors which affect the frequency of inspections.

Fundamentally, conventional inspection processes are often labour intensive, time-consuming, and costly procedures subject to the expertise and experience of the inspection team (Al Zaabi *et al.*, 2022; Thirusanku and Ki, 2022). According to Nena *et al*., (2021) and Olojede, Agbola and Samuel, (2019), the lack of experienced inspection professionals in South Africa adds to the rate of failures in the delivery of quality housing. Thus, it is evident that the above-mentioned inefficiencies are borne largely by human limitations in the human capacity to carry out the inspections effectively and sufficiently without fallibility.

2.2.3. The evolution of inspection practices in construction

The evolution of construction inspections has been driven by the need for higher quality and safety standards as necessitated by regulatory requirements as well as advancements in technology (Rolfsen and Lassen, 2020). The earliest form of construction inspections involved the informal appointment of an inspector with the responsibility to oversee the implementation of a construction project according to required codes and standards (Ciampa, De Vito and Rosaria Pecce, 2019; Kazaz *et al.*, 2021). However, with the increasing world population and the growth in demand for housing and infrastructure, new materials and construction techniques were developed.

Hence, governments around the world placed more stringent regulations and building codes to ensure the safety of the occupants, durability, and sustainable building practices (Alaloul *et al.*, 2021). With more emphasis on quality, construction professionals had to adopt more formalized inspection practices to ensure compliance to these regulations (Sidani *et al.*, 2021). Thus, trained experts were employed to manually traverse construction sites to assess the quality of the works and adherence to building codes and standards.

However, the laborious and subjective nature of these practices introduced paper-based inspections with checklist and forms used as standardized means of ensuring a consistent approach to inspection practices (Hussamadin, Jansson and Mukkavaara, 2023). Even so, these methods remained cumbersome to manage and share thereby necessitating visual documentation through photography. Advancements in reality capture technologies and digital tools in non-destructive testing (NDT) sensors and laser scanners have been introduced to the world of construction inspections since the turn of the 21st century (Li *et al.*, 2019). In their nascence, these technologies relatively improved the degree of accuracy in traditional inspection practices and enabled comprehensive site conditions inspections, resulting in the production of large quantities of datasets (Zhou and Gheisari, 2018; Alaloul *et al.*, 2021; Parsamehr *et al.*, 2023). However, their limitations in the capability to process discovered datasets meant that inspectors had to thoroughly review the detected deviations against the project specification requirements in order to understand their importance. Thereafter, the inspector could perform guided measurements and assessment of violations to create a defect report referencing deficiencies (Ding *et al.*, 2017).

Recently, professionals within the construction industry have been actively exploring various approaches to improve construction inspections by adopting cutting-edge technologies, such as deep learning-based object detection and embedded sensors (Pal and Hsieh, 2021; Greeshma and Edayadiyil, 2022). Through research and design, these automation technologies aimed at reducing construction project related risks associated with hazards and noncompliance. Inherent to this pursuit, inspection practices have been fuelled with the introduction and fine-tuning of methods for identifying and managing defections for effective detection of faults (Ma *et al.*, 2018).

Since then, many propositions have emerged to improve data collection, sensing, and visualisation for on-site inspections. These proposals involve integrating automated data acquisition technologies with scheduling systems and relational databases like CAD and BIM (Walasek and Barszcz, 2017; May *et al.*, 2022). Below are some examples of the above-mentioned techniques and technologies that are extensively used for construction site inspections.

Close contact Non-destructive testing (NDT) methods for inspection

Close Contact Non-Destructive Testing (NDT) is an inspection technique that involves direct physical access to an area of inspection to enable a comprehensive evaluation of structures, components, materials, or systems (Zainudin, 2018; Falorca and Lanzinha, 2020). According to El Masri and Rakha (2020), visual inspection procedures with the naked eye of optical gadgets are the most basic NDT techniques used to inspect surface-related defects. However, special apparatus and sensors are used to assess properties at the region of inspection for characteristic differences, defects, and discontinuities without causing damage to the component (El Masri and Rakha, 2020). NDT has revolutionised inspection practices through precision and reliability in assessing the integrity of structures and materials. Inherently, the component is not changed or destroyed and is still fit to serve its purpose after testing, making them essential tools in the construction inspection processes (Nooralishahi *et al.*, 2021).

In particular, NDT emerged as a critical tool in the construction industry, revolutionising quality control and safety inspections. Notably, they provided quantitative measures of structural integrity through the identification of hidden defects that could result in catastrophic failures and/or harm to workers and occupants (Tejedor *et al.*, 2022). Thus, producing evaluations that are more reliable in enabling the mitigation of construction defects, costly reworks and delays (El Masri and Rakha, 2020; H. Chen *et al.*, 2021).

Although NDT also encompassed visual inspections, ultrasonic testing, magnetic particle testing, ground penetrating radar, thermography, radiographic testing, acoustic impact echo and dye penetrant testing have been implemented for construction related inspections (Dwivedi, Vishwakarma and Soni, 2018; Feroz and Abu Dabous, 2021; Nooralishahi *et al.*, 2021). Dwivedi, Vishwakarma and Soni, (2018) explains that these techniques can be done on an array of metals, ceramics, concrete and coatings in orders to identify flaws such as defective welds, internal voids, cracks and surface delamination. Table 2.2 below defines these techniques in detail and their suitable applications in construction site inspection cases. Moreover, table 2.2 also highlights the limitations that are associated with these methods.

Table 2.2: Close contact NDT techniques and their applications

NDT Technique	Definition	Most suitable application	Limitations
Ultrasonic testing (UT)	Detecting material defects by introducing high-frequency sound waves to identify changes in properties (Gupta *et al.*, 2022; Tejedor *et al.*, 2022).	Welds, corrosion, concrete flaw detection.	Only suitable for materials that are good conductors of sound (Dwivedi, Vishwakarma and Soni, 2018).
Magnetic particle testing (MT)	MT uses magnetic fields to examine discontinuities in ferrous materials (Feroz and Abu Dabous, 2021; H. Chen *et al.*, 2021).	Surface/near surface defects in steel & iron	Can only be performed on ferromagnetic materials. Subsurface capabilities are limited (Dwivedi, Vishwakarma and Soni, 2018).
Ground Penetrating Radar (GPR)	GPR employs radar pulses to investigate subsurface conditions (El Masri and Rakha, 2020; Oikonomopoulou *et al.*, 2022).	Soil conditions, concrete, asphalt, underground utilities	Accuracy depends on the type of soil. Difficult to interpret and understand results (Oikonomopoulou *et al*, 2022).
Thermography (TT)	Using thermal cameras to capture and visualize infrared radiation emitted by objects and surfaces (Tejedor *et al*, 2022	Insulation issues, water/air leaks	Too difficult to apply in larger structures (Dwivedi, Vishwakarma and Soni, 2018).
Radiographic Testing (RT)	Internal structure is examined using gamma rays or x-rays on materials to identify imperfections (Dwivedi, Vishwakarma and Soni, 2018).	Welds, concrete, composites, steel	May require radiation protection (Dwivedi, Vishwakarma and Soni, 2018).
Acoustic emission testing (AE)	Monitoring and analysing acoustic waves/sounds generated by energy released from a material when subjected to stress (Dwivedi, Vishwakarma and Soni, 2018; Gupta *et al.*, 2022).	Reinforced concrete, welds, corrosion.	Requires expensive equipment and may be difficult to interpret results (Tejedor *et al.*, 2022).
Dye penetrant testing (PT)	Spraying liquid dye to assess detection of surface-breaking defects, cracks, and discontinuities in materials (El Masri and Rakha, 2020).	Metals, plastics, ceramics.	Not suitable for porous materials. Cannot detect subsurface flaws (Tejedor *et al.*, 2022).

According to Gupta *et al*, (2022) NDT techniques became indispensable in construction inspections as they ensured structural integrity and safety of components and materials, maintaining quality and conformance to standards. Furthermore, while enabling early detection of defects, the data from evaluations enable informed decision-making throughout the construction lifecycle. Nevertheless, safety risks and the accessibility challenges still remain for human led NDT inspections. As a result, NDT has embraced digital and robotic inspection platforms in order to expand the utility of NDT technologies (Zollini *et al.*, 2020; Nooralishahi *et al.*, 2021; Gupta *et al.*, 2022). Increasingly, NDT methods are being applied on robotic systems such as drones to capture valuable data in confined spaces, hard-to-reach, or hazardous areas (Zollini *et al.*, 2020; Falorca, Miraldes and Lanzinha, 2021a; Feroz and Abu Dabous, 2021).

BIM-based on-site inspection

Numerous scholars argue that BIM-based technologies can improve inspection processes by offering inspection personnel efficient procedures to meet assessment requirements and comply with mandatory standards (Ding *et al.*, 2017). Several technologies including Light Detection and Ranging (LiDAR), Augmented Reality (AR), and web technology have been integrated with BIM to support inspection practices (Sidani *et al.*, 2021; May *et al.*, 2022). In particular, the combination of BIM and AR has resulted in the creation of defect management systems that use image-matching techniques to detect defects during inspections. (Kwon, Park and Lim, 2014; Hajdukiewicz *et al.*, 2019; Zhou, Liu and Ren, 2020). For instance, Martínez-Rojas *et al*, (2016), Ding *et al*, (2017), Ma *et al,* (2018) and London et al, (2021) integrated scheduling functionalities with quality management process models which were able to inspect, test, and report nonconformance, and dispense the necessary information required to take corrective action through BIM.

Nevertheless, the incorporation of quality information alongside other project-related data continues to pose a significant obstacle (Hajdukiewicz *et al.*, 2019). This occurs due to the presence of diverse data representations and formats. As a result, interoperability issues arise, necessitating the use of industry foundation classes enabled schemas and algorithms like Convolutional Neural Networks (CNN) to facilitate information exchange (Arashpour, Ngo and Li, 2021; Teng and Chen, 2022; Zhu, 2022).

Deep learning-based object detection

Object detection with deep learning refers to an immersive computer vision technique that locates and identifies multiple objects within an image or video footage by a process of categorization ad localization (Teng and Chen, 2022). It entails training models derived from region-based convolutional neural networks (R-CNN) and single-stage neural network YOLO (You Only Look Once) and Single Shot identification (SSD)) with a myriad of annotated pictures to identify and locate objects within images or videos by recognizing underlying patterns and specific features (Shanti *et al.*, 2021). Likewise, Alzubaidi *et al.*, (2021) and Arabi, Haghighat and Sharma, (2019) both describe deep learning-based object detection as a powerful machine learning approach propelling advances in applications including scene understanding, surveillance and autonomous systems.

Fundamentally, deep learning-based approaches are employed as a tool in construction projects to automate and advance inspection processes that involve: (1) structural damage detection (Munawar *et al.*, 2022); (2) surface crack detection (Arabi, Haghighat and Sharma, 2020; Dias, Flores-Colen and Silva, 2021; Zhang *et al.*, 2022; Zhu, 2022); (3) equipment detection for safety improvement (Arabi, Haghighat and Sharma, 2020; Arashpour, Ngo and Li, 2021; Shanti *et al.*, 2021); (4) as well as on-site personnel behaviour analysis such as non-compliance to PPE (Fang *et al.*, 2020; Nath, Behzadan and Paal, 2020). Consequently, deep learning-based object detection has become prominent in the construction industry as it is able to streamline otherwise laborious and resource-intensive inspections, providing valuable information for semantic understanding of inspection images and videos from a construction site environment (Dias, Flores-Colen and Silva, 2021).

However, the performance of these models largely depends on the availability of training data for fine-tuning and accuracy improvement (Katsigiannis *et al.*, 2023). Consequently, inspectors would need to fine tune pre-trained models through a process called transfer learning (Katsigiannis *et al.*, 2023; Kaur and Singh, 2023). Thus, no standardized model can be applied across the entirety of construction site inspections without being fine-tuned. In that sense, addressing these challenges would require a blend of innovative training strategies and quality training data which necessitates the development of new techniques and the modification of existing ones.

Smart sensors

Recently, monitoring sensors, tags and 3D scanning systems have been developed for construction inspections to enable continuous quality checks throughout the project life cycle. Per se, these are advanced IoT devices and systems integrated into building structures and materials to monitor and provide real-time data on various aspects of the construction processes (H. Chen *et al.*, 2021). From the onset of the construction phase, smart sensors can be essential in monitoring concrete curing process as well as detecting changes in the physical conditions of structures and monitoring worker's health and safety (Hajdukiewicz *et al.*, 2019).

Furthermore, they monitor penitential risks on site, environmental impact assessment, and resource usage. Consequently, they play a crucial role in enhancing safety, efficiency, and sustainability in the construction project delivery process (Ghosh, Edwards and Hosseini, 2020). While embedded sensors offer significant benefits, they also come with challenges. These include initial costs, data management, and the need for specialized expertise to install and maintain the sensors (Bornemann and Lang, 2022). Additionally, ensuring data security and privacy is crucial, as these sensors collect and transmit vast amounts of data, some of which could be sensitive or proprietary (Hajdukiewicz *et al.*, 2019).

As presented in literature, these methods and techniques employed by inspectors to aid them during inspection processes present certain limitations and challenges. Hence, table 2.3 provides a summary of the limitations that are related to these standard computer-vision based inspections.

Table 2.3: Limitations related to standard computer-vision based inspections

Method	Limitation/Challenge	Explanation
(NDT) methods for inspection	Temporary access equipment	Scaffolding and access equipment still needed for inspection (Nooralishahi *et al.*, 2021).
	Safety	Inspectors still need to access hard-to-reach areas, confined spaces, etc(Gupta *et al.*, 2022).
BIM -enabled on-site inspection	Data Accuracy & Integration.	Effectiveness of BIM relies on accuracy & integration of data from various sources (Chen and Lu, 2019).
	Interoperability Issues	Incompatibility of software and tools from different vendors lead to operational issues (Lee, Park and Song, 2018).
	Unforeseen Conditions	Discrepancies between model & actual construction due to unforeseen site conditions (Comiskey *et al.*, 2018).
Deep learning-based object detection	Variability in object appearance.	Achromatic characteristics of objects under lighting, viewpoints, backgrounds (Alzubaidi *et al.*, 2021; Munawar *et al.*, 2022).
	Scale variations:	Complexities in object detection between small and large objects in the same image (Kaur and Singh, 2023).
	Intra-class variability:	Scale invariance requires multi-algorithm integration for intra-class variations (Amjoud and Amrouch, 2023; Kaur and Singh, 2023).
	Background clutter:	Most not suitable for high noise, low contrast environment with multiple overlapping objects (Kazaz *et al.*, 2021; Babu *et al.*, 2023).
	Occasion:	Slow rate of defect detection due to partial/complete obscurity or environmental interferences (Silva and Lucena, 2018; Dias, Flores-Colen and Silva, 2021).
Smart sensors	Data management systems compatibility.	Integration with existing legacy systems can be costly and disruptive (Shanti *et al.*, 2021).
	Need for specialized expertise	Effective utilisation requires substantial training and skills development (H. Chen *et al.*, 2021).
	Privacy and data security.	Vast amounts of sensitive or proprietary data must be securely stored and transmitted (Ghosh, Edwards and Hosseini, 2020).
	Conductivity issues	Electrical short circuits due to conductivity of surrounding material (H. Chen *et al.*, 2021).

In essence, construction inspection methods are derived from the requirements that construction specifications impose on a construction project (Ding *et al*, 2017). These requirements outline elements to be inspected and indicate the degree of accuracy for measurements relating to required tolerances. Thus, influencing the choice of methods to be implemented for certain inspections. Fundamentally, knowing the stipulated requirements enables the inspection personnel to assess the significance of deviations that are discovered on construction sites (Wang *et al.*, 2016; Xu *et al.*, 2019; Zhou, Liu and Ren, 2020).

2.2.4. Classifications of construction inspection standards in South Africa

Development in construction is continuously advancing. Through the years new materials are being developed, design methods are being improved, and innovative construction processes are introduced (Elhouar and Terreno, 2022). Inherently, construction regulations are set out to classify elemental necessities to guarantee that buildings are planned and built in a manner that allows individuals to occupy a healthy and safe environment, while encouraging innovative design, the usage of new materials and suitable construction approaches (SABS, 2021). However, there are other aspects of a building such as acoustic or thermal performance that are judged subjectively and are not as easily amenable through regulation. Hence, standards are publicly available documents incorporating technical specifications and criteria intended for consistent use as a rule, guideline, or definition (Comiskey *et al.*, 2018; Lu *et al.*, 2022b). These standards aim to enhance the quality, dependability, and efficiency of various goods and services. Moreover, they provide a broader range of choices and facilitate easier access to these goods and services (Nena, Musonda and Okoro, 2023).

Furthermore, the international standard that the construction industry applies for quality inspection is the ISO9000 family of standards (Perez, Zech and Donald, 2015). The standard details technical guides, specifications and reports relating to the effectiveness of quality management systems for organisations. Fundamentally, project scope, budget and schedule determine the management of inspection quality standards (Lin *et al.*, 2020). On the other hand, the ISO standard that guide H&S inspections is the ISO45001 which provides a framework for managers to protect the health and safety of workers (Fahmi *et al.*, 2021; Karanikas *et al.*, 2022). These inspections are carried out by a H&S officer, H&S advisor, or a risk assessment manager (Nielsen, 2017; Umar, 2021).

In South Africa, SANS10400, which is the application of the national building regulations, is used as a primary guide to construction works, processes and systems (CIDB, 2021). Hence, specific inspections are structured in compliance with the above directive regardless of internal or external (third party or regulatory body) inspection measures. Checks for materials, work units, processes, and services that have been created and planned by the construction project team to meet with the contract's quality standards may be included in construction inspections linked to quality control (Tan *et al.*, 2021). Conversely, H&S inspections are largely guided by the Occupational Health and Safety (OHS) Act 85 of 1993 (with amendment OHS ACT 181 of 1993) (SABS, 2021; Malomane, Musonda and Okoro, 2022). This Act governs H&S regulations across all environments including hazardous environments such as construction sites and industrial plants.

In order to comply with the National Building Regulations, it is necessary to adhere to both the prescriptive regulations and the functional regulations. This can be achieved by either using building solutions that align with the provisions of the relevant part of SANS 10400 or by reliably demonstrating that an alternative building solution performs equally or better (Nena, Musonda and Okoro, 2021, 2023). When local authorities require compliance with regulations, a qualified professional registered under relevant Acts, such as the Architectural Professions Act, 2000 (Act No 44 of 2000), the Engineering Profession Act, 2000 (Act No 46 of 2000), the Natural Scientific Professions Act, 2003 (Act No. 27 of 2003), or other applicable Acts, should prepare and submit a thorough inspection. This inspection should consider various criteria, including the structural system, artificial ventilation system, drainage installation, stormwater or surface water drainage system, fire protection system, or water supply system, as relevant to the specific context (SABS, 2021).

Furthermore, an approved competent person, meeting the requirements as per the above-mentioned must inspect and certify the construction or installation of a system or facility in accordance with the conditions of SANS10400-A (SABS, 2021). A professional registered in accordance with one of the councils specified in the Council for the Built Environment Act, 2000 (Act No. 43 of 2000) generally employs guidelines highlighted below to satisfy the applicable functional regulations throughout the project phases (SABS, 2021).

Pre-construction:

- Obtain and utilise an approved plan to thoroughly assess the building's adherence to legal regulations.

Throughout the construction process

- Before pouring the foundation, it is important to thoroughly examine the soil condition, as well as the depth and width of the footings. This should be done in accordance with the rational design and performance requirements outlined in the National Building Regulations.
- Examine the building construction to ensure it meets the standards set by the National Building Regulations in terms of foundation/slab, brickworks, roof structure, and services.
- Ensure that structures and fixtures are properly aligned and elevated to meet building compliance standards.
- Detect and address instances of non-compliance in building construction and usage.

  Choose appropriate tools to assess the quality of building materials and products.
- Identify, record, and compile reports.
- Prepare court reports regarding violations of legal and regulatory requirements in building construction.
- Assist in legal proceedings by preparing cases and providing testimony in a court of law.

  Post construction:
- It is important to thoroughly examine the structural integrity of the building.
- Examining the quality of building materials.
- Prepare a comprehensive report summarizing the findings.

- Co-ordinate site inspections and approvals with other departments (fire, electrical, health, sewerage).

Hence, different standards are in place to govern construction quality management practices. While these standards may differ between the different types of construction environments defined by scale and complexity, their fundamental essence remains constant—mandating inspections following significant construction procedures through cooperative efforts among project stakeholders (Ma *et al.*, 2018). In this context, contractors are tasked with conducting the initial assessments, while regulatory bodies such as the National Home Builders Registration Council (NHBRC) bear responsibility for subsequent assessments in terms of adherence to building codes and regulations (Nena, Musonda and Okoro, 2023).

2.3. Quality inspections during project execution

The importance of quality in construction cannot be ignored as it pertains to the lives and safety of the occupants within the built environment. According to Salvi and Kerkar, (2020), insistence on comprehensive inspections and quality testing programs during project execution should be the intent of every client. Likewise, quality control is an inherent duty for the construction project management team (Ali, Mubin and Gavrishyk, 2022). Therefore, to maintain quality, the project manager delegates the responsibilities for quality to contractors.

Although adequate on-site inspections are usually proposed as part of the contractual agreement, the contractor usually relies on the subcontractors to maintain quality control, and contractual clauses are imposed to resolve quality related issues (Donato, Lo Turco and Bocconcino, 2018). This contractual relationship may be confusing at times, be the subject of litigation or even be the basis of the failure of the end product in conforming to certain quality standards. However, necessary quality control can be affected through the development of a quality control plan which emphasizes inspection services (Ribah and Singh, 2023). Nevertheless, there is a need for more clarity in studies that have examined the relationship between schedule, and quality management, schedule and physical objects in the context of inspection processes. Additionally, challenges have been identified in facilitating control of quality monitoring in real time (London, Pablo and Gu, 2021; Ali, Mubin and Gavrishyk, 2022).

As presented by the literature, inspections are a vital part of quality control and the necessary quality management systems can lead to effective quality control procedures. Accordingly, quality control inspections can be conducted at three different phases of an activity during project execution (Ding *et al.*, 2017; Ribah and Singh, 2023). The first stage is inspection and testing of materials received or work prepared before the activity starts. Inspectors assess the specifications, certifications and condition of materials and equipment to ensure that they meet the required industry standards and are suitable for the intended use. The second stage is inspection and testing of work-in-progress where the focus is in verifying that construction works aligns with the approved drawings, including structural integrity and dimensions to maintain consistency and compliance with specifications. Lastly, functional tests, load tests, and system checks are conducted to verify that completed component operate efficiently, meet performance requirements, and comply with project specifications and industry standards (Hajdukiewicz *et al.*, 2019; Salvi and Kerkar, 2020).

2.3.1. The need for physical quality inspections by professionals

The construction industry, marked by its complexity and evolving standards, demands attention and commitment to quality. As opined by Lu *et al.*, (2022b) and Ding *et al.*, (2017) maintaining integrity and safety of the built environment requires a vigilant systematic approach, with physical access to points of interest for an inspection undertaken to achieve assessment of the parameters. By physically navigating the construction site, inspectors can witness first-hand the status of various activities and document any nonconformances (Olanrewaju, Khor and Preece, 2021; Pal *et al.*, 2023). Thus, the visual insights allow for immediate documentation if deviations from the plan are identified. With the expertise and experience that they possess, inspectors are able to verify that construction activities align with established standards and regulations, building codes, safety guidelines, and environmental regulations (Agnisarman *et al.*, 2019).

Furthermore, professionals employ systematic processes such as the one presented in figure 2.1 to identify potential defects or issues, assess the quality of materials, workmanship, and adherence to design specifications, addressing concerns before they compromise the integrity of the structure (Guo and Wang, 2022; Shin and Cha, 2023). Thus, providing measurable and subjective assessments of defects which contributes to the optimisation of construction processes. This proactive approach of systematically assessing and mitigating risks not only enhances the safety of the construction site but also minimizes the chances of accidents, delays, and financial losses (Zhang *et al.*, 2022).

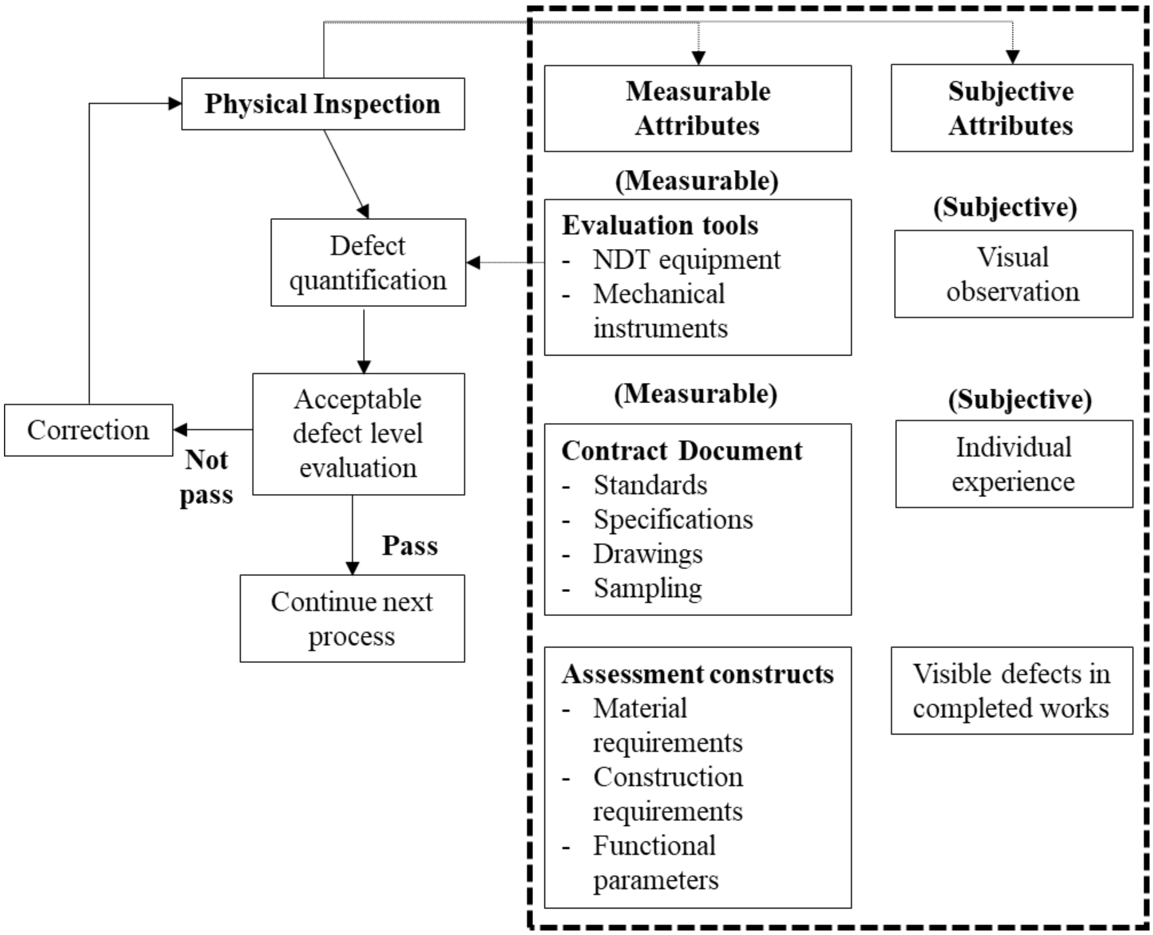

Figure 2.1: Construction site physical quality inspection process (adapted from (Liu et al., 2023; Shin and Cha, 2023)

However, the physical process of inspecting quality still faces challenges in terms of determining acceptable defect levels, particularly when it comes to differing opinions among individuals involved and the need for access equipment to inspection areas

(Arashpour, Ngo and Li, 2021). According to Liu *et al*, (2023) assessing the quality of construction work physically involves measurable and subjective attributes as is shown in figure 2.1 above. Measurable attributes encompass materials and functional requirements, which must adhere to standards and specifications detailed in the contractual document (Liu *et al,* 2023). Given their quantifiable nature, non-destructive testing instruments, such as those described under section 2.2.3, are often employed to enhance human judgment by providing precise measurements.

On the other hand, the subjective attribute pertains to perceived visible defects (Lu *et al.,* 2022b). In this manner, quality inspections rely solely on subjective visual evaluations by the inspection personnel. Therefore, the ability to judge defects or nonconformities is constrained as it cannot be quantified (Hussamadin, Jansson and Mukkavaara, 2023). Hence, the evaluation is nonuniform and depends on individual experience.

Consequently, strategies need to be developed to address the need for access equipment to points of interests and the limitations due to subjectivity in quality inspections (Dias, Flores-Colen and Silva, 2021). Nevertheless, Falorca *et al*, (2021) argue that there is a clear necessity to systematically and comprehensively collect and report data from construction site inspections. Moreover, it is imperative to store this data in an easily accessible and well-structured format to maintain the quality of inspections. According to Mathern and Magnusson, (2022), such an approach facilitates the transformation of experience into knowledge, which can then be applied in subsequent projects through the analysis of the gathered data.

In particular, incorporating modern technologies such as robotics into physical inspections to enhance the efficiency and accuracy of the inspection process. Essentially, integrating advanced tools such as drones, sensors, and digital documentation systems to allow professionals to gather and analyse data more efficiently(Falorca, Miraldes and Lanzinha, 2021a; Mathern and Magnusson, 2022; Halder and Afsari, 2023). This not only improves the accuracy of inspections but also provides a comprehensive view of the construction site turning knowledge into information.

2.3.2. Conventional quality inspection Process

During the inspection and acceptance of construction works, three types of information are collected and shared. The first type includes physical objects like equipment and components that are relevant to the construction processes. The second type is schedule information that adds a temporal dimension to inspection activities by focusing on project tasks. Lastly, quality management information encompasses inspection data and acceptance decisions (Teijón-López-Zuazo *et al.*, 2020).

Scope specific visual observations and checks are carried out by the quality control inspector, project management team or third-party inspector using visual aids and non-destructive tools and apparatus to detect defects (Feuge-Miller and Jah, 2022). Quality related issues in the works, materials and equipment are evaluated using methods such as the six sigma and quality control checklists to ensure conformance to SANS10400 and ISO9000 family of standards, and for assurance before external quality inspectors can be brought in (Nena, Musonda and Okoro, 2021).

Figure 2.2 illustrates the typical sequence, where the construction management team develop an inspection plan outlining inspection activity, check items, and corresponding target objects prior to the commencement of construction works (Lu *et al.*, 2022b). At each phase of the construction works, the contractor conducts checks on the target objects with respect to the check items outlined in the inspection plan. During these checks inspection results are documented for each target object using paper-based on-site checklists and forms. Subsequently, an inspection activity checklist form containing brief inspection results is completed and submitted to the supervisor.

However, significant details about each target object are not included (Nasseri and Aulin, 2016). The project manager/principal agent verifies the inspection results before the contractor proceeds to the next phase of construction works. For critical inspection activities, verification may be conducted by the client. Thus, inspection checklists, on-site forms and inspection activities checklist forms act as crucial inspection documents, certifying construction quality and designating responsible individuals. To maintain the clarity of inspection data, the checklist forms need to be printed and signed by relevant inspectors from stakeholders involved (Rouhanizadeh and Kermanshachi, 2020; Teijón-López-Zuazo *et al.*, 2020).

When nonconformances are identified, they are recorded for work which cannot be fixed immediately or where rework or repairs have to take place. Nonconformance reports (NCRs) completed typically identify the originator, date raised, location and person responsible to address the problem including the process for which the nonconformance was raised, and the disposition of the nonconformance (Grosso *et al.*, 2020). The nonconformance and actual cause of the problem should be determined, and the necessary steps needed to address the problem and stop the problem from recurring identified. Furthermore, a corrective action plan is reported, and the results are reviewed for approval before proceeding with subsequent activities (Grosso *et al.*, 2020; Lu *et al.*, 2022b). On the other hand, the challenge lies in the timely and accurate communication of nonconformance information and corrective actions among stakeholders, often involving heavy paperwork and communication (Hatoum *et al.*, 2021).

According to Ding *et al*, (2017), the conventional practice of quality inspection in construction often involves post-activity assessments. However, quality inspection ought to be an ongoing procedure carried out in real time throughout construction management activities. As presented in literature, resource constraints may hinder real-time monitoring, leading to delayed identification of nonconformance and potentially exacerbating the need for rework. According to May *et al.*, (2022), an efficient information management system is crucial in order to enhance productivity, especially when third-party audits are required for inspections. In this regard, Faraji *et al.*, (2022) and Lee and Kim, (2018) argue that the management of relevant information, including activity details, inspection and test plans, work plans, checklist results, and NCR, is essential for stakeholders to easily track quality inspection results and their causes, emphasizing the need for a process-oriented approach in quality management.

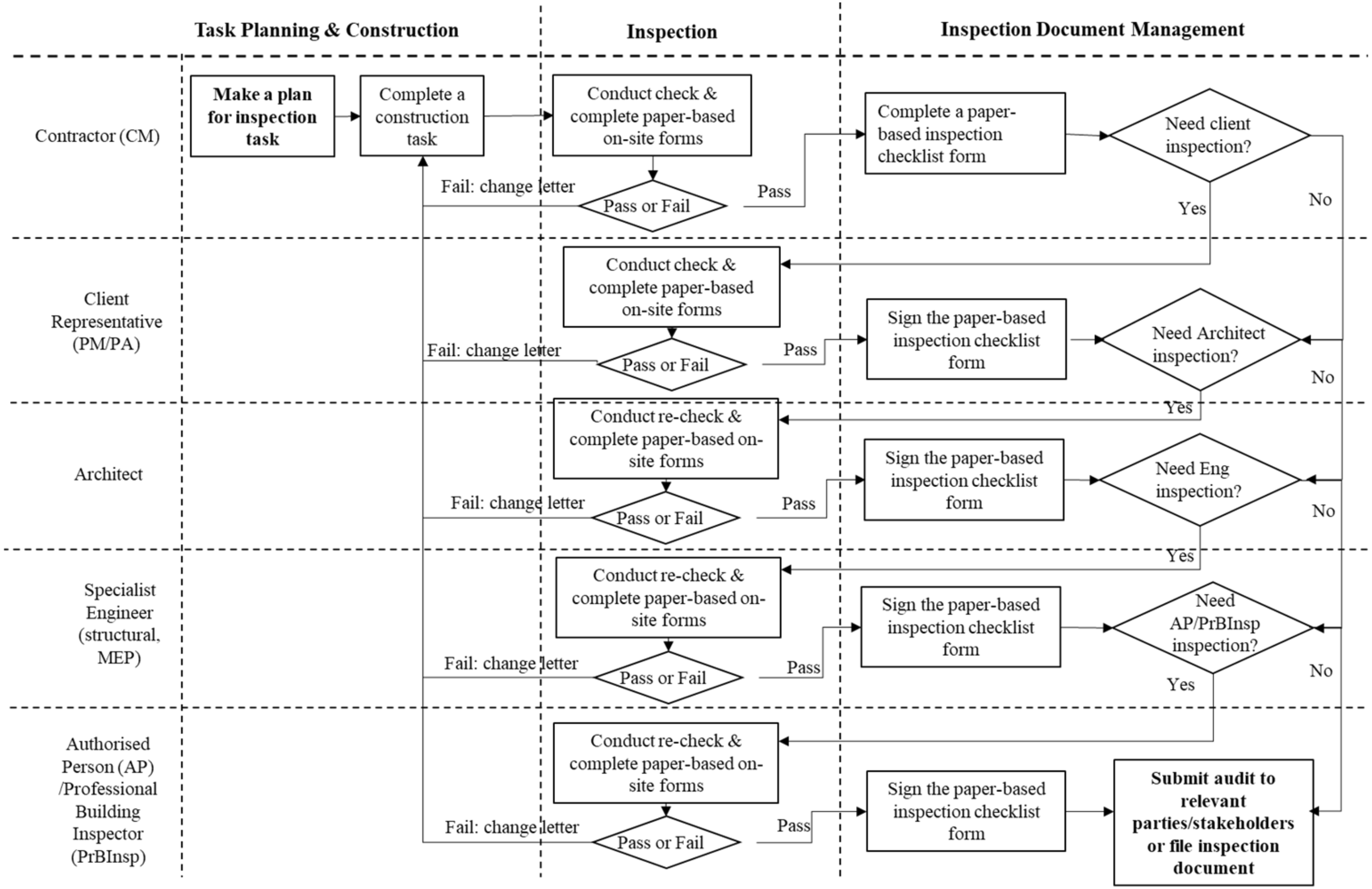

Figure 2.2: Typical construction site inspection process (Adapted from Lu et al, 2022)

2.3.3. The limitations with existing quality inspection processes: How physical inspection prevents real-time collection of site data

Limitations in CSM refer to management shortcomings that arise from the site management's inability to effectively oversee the construction site management process. These limitations have an impact on how the construction contract is administered (Ozumba *et al.*, 2019). Shortcomings originate from “limitations in the human capacity to ally, direct, track, monitor and control the activities of operatives, movement and utilisation of resources on site” (Ozumba and Shakantu, 2020). Crescenzi and Gagliardi, (2018) assert that addressing these limitations necessitates the adoption of technological innovations. Ozumba *et al.*, (2019) also argue that incorporating technology on construction sites is necessary to effectively address these shortcomings.

Undoubtably, conventional inspection procedures suffer from critical lapses. To this effect, limitations are related to the reluctance to adopt more technologically advanced methods, the lack of consistency due to subjective factors, concerns about the integrity of information and data, and the manual collection of inspection data, among other factors (Dallaqua *et al.*, 2021; Onososen *et al.*, 2023). Accordingly, in construction projects, human error and change orders are unavoidable (Xu, 2021). Therefore, a thorough inspection system that addresses faults and required modifications is crucial to the value of quality control inspections.

As stated above, human error cannot be prevented while performing manual-based inspections due of the aforementioned limitations (Nielsen, 2017; London, Pablo and Gu, 2021). The biggest obstacle to effective and high-quality inspections is having inefficient and inaccurate inspection data (Ekanayake *et al.*, 2021; Suleiman, 2022). Generally, the existing quality inspection processes are normally time-consuming, necessitating the disruption of on-going construction site activities. Consequently, the conventional procedures face limitations regarding time constraints and access requirements. Additionally, conventional inspection processes tend to be subjective, with the accuracy of findings relying on the skills and experience of the inspection personnel.

Thus, in the absence of relevant quantitative information, qualitative data offer limited insights (H. Chen *et al.*, 2021). Aside from that, the COVID-19 epidemic has complicated inspection processes, forcing project management professionals globally to consider new methods of inspection(Razafimahazo *et al.*, 2021). Moreover, significant constraint in current inspection approaches is the limited accessibility of infrastructure systems where considerable expense is necessary for obtaining visual access to critical system components (Albeaino and Gheisari, 2021).

To address the above-mentioned issues, Albeaino and Gheisari (2021) as well as Martinez *et al*, (2020) suggest that it is strongly recommended that the construction industry embraces a systematic site inspection approach utilizing information, communication, and technology (ICT) tools to enhance inspection process efficiency. This becomes particularly critical when dealing with projects requiring detailed inspections due to contractual specifications, intricate designs that involve substantial changes in site inspection measurements, and regulatory requirements as stipulated by the local authority (Sermet and Demir, 2019; Martinez, Gheisari and Alarcon, 2020; Albeaino and Gheisari, 2021; Dai *et al.*, 2021). Table 2.4 below presents limitations relating to human shortcomings in conducting physical construction site inspections.

Table 2.4: Limitations on current site inspection processes

Factor	**Consequences**
Lack of appropriate quality assurance procedure	Quality control has major impact on schedule performance, especially when important items are overlooked. (Nielsen, 2017; Lin and Fan, 2018; Rouhanizadeh and Kermanshachi, 2020; Rey, de Melo and Costa, 2021)
Human Error	Misjudgement of defects Failure to implement quality control checklist Failure to properly record inspections. (Kazaz *et al.*, 2021; Tekin, 2022; Halder *et al.*, 2023)
Change orders cause delays in the process	Change orders from inefficient and inadequate inspections lead to excessive delays. The challenge of suggesting timely corrective and preventive measures. (Rouhanizadeh and Kermanshachi, 2020; Safapour, Kermanshachi and Kamalirad, 2020; Rey, de Melo and Costa, 2021)
Manual data collections and communication	Paper-based inspection makes the process inefficient and time consuming. Procedure risk factors have potential consequences such as curtail defects in building services. Large amount of work required for inspection data collection and communication.

	Lack of real-time communication of defects detection Information may be lost between inspection event and processing. Lack information sharing among project stakeholders. High demand data with manual transcription. Late delivery of feedback and control reports. (Lu et al., 2022; Mohamed and Tran, 2022; Palacios et al., 2018; Comiskey et al., 2018; Engler Bridi et al., 2021; Olanrewaju et al., 2021)
Limited number of inspectors	Difficulty in proposing corrective and preventive measures in real time. Inadequate number of inspectors responsible for the related project. (Zhou and Gheisari, 2018; Rey, de Melo and Costa, 2021)
Lack of specialized inspectors	Limited number of inspectors to dedicate to projects due in part by insufficient specialized inspectors. Data inconsistency during inspection. (Hatoum *et al.*, 2021; Albeaino, Gheisari and Issa, 2022)
Lack of appropriate training programs	Not enough training, specifically for the new inspectors Weaknesses in contractor outsourced for key project inspection leads to delays and increased project budget. (Rouhanizadeh and Kermanshachi, 2020; Mohamed and Tran, 2022; Suleiman, 2022)

2.3.4. Underlying quality inspection challenges that drone adoption can resolve

According to Lin and Fan, (2018), site inspections are often regarded as a "necessary evil," another task in a long list of jobs to do to maintain contractual obligations and regulatory compliance. Although meant to ensure quality of work on-site, personnel are often exposed to exterior elements; unfavourable conditions; intrinsic risks like as being suspended from substantial heights; working around inherently unstable structures; and working in and around water (Rouhanizadeh and Kermanshachi, 2020; Tan *et al.*, 2021; Suleiman, 2022).

Moreover, it is believed that project stakeholders lack exposure to methods that could enhance their expertise in quality control inspections of construction works (Ameli *et al.*, 2022; Mohamed and Tran, 2022). For example, Mohamed and Tran, (2022) states that for bridge inspectors to perform safe inspections with reduced risk and hazards, extensive training is necessary. Existing literature generally points out significant deficiencies in the inspection process for construction projects during the execution stage.

However, it is equally crucial to examine the obstacles that hinder effective and high-quality inspections. Key factors to efficient and quality inspections are described in table 2.5 below. According to Suleiman (2022) these factors are exacerbated by the human limitations described above. Hence, authors such as (Falorca and Lanzinha, 2020; Kim and Irizarry, 2020; Ekanayake *et al.*, 2021; Falorca, Miraldes and Lanzinha, 2021a; Rey, de Melo and Costa, 2021, 2021; Tan *et al.*, 2021) suggest that the implementation of drone technology could address these challenges through the elimination of the challenges under table 2.5 and limitations as sated under table 2.5.

As illustrated in table 2.5, when using rope access or swing stages in the traditional inspection method, contractors are responsible for covering the costs of access equipment, climbing gear, insurance, and any extra labour required (Falorca and Lanzinha, 2020). As buildings increase in height, the use of ladders becomes insufficient for larger and taller structures. Consequently, there is a requirement to invest in more expensive access and safety equipment to mitigate the associated risks (Tekin, 2022). Accordingly, it becomes harder, riskier, and more expensive to conduct inspections as structures become more complex. Additional safety considerations involve the risk of coming into contact with overhead power lines and the potential for falls while attempting to ascend the roof (Paneru and Jeelani, 2021).

As a result of these escalating hazards, the costs associated with tools, personnel, and insurance policies for inspection personnel increase. However, the inspectors continue to face challenges in acquiring comprehensive details about certain surfaces (Tekin, 2022). Nielsen, (2017) states that this is occasionally caused by inspectors' inability to access surfaces or structures to optimal proximity, enclosed spaces, or places where their climbing equipment cannot reach. Intrinsically, accurate data gathering is crucial for improved project quality control and future reference. The purpose of the automated site inspection system through drone technology would be to increase quality control inspection efficiency, opening up opportunities for an automatic shift from quality control (periodic inspection of work done) to quality assurance (real time monitoring of work done) (Donato, Lo Turco and Bocconcino, 2018; Shariq and Hughes, 2020).

Table 2.5: Challenges with resources used for typical assessments in traditional inspection practices (adapted from Falorca et al, 2020)

Type of construction site	Assessment issues justifying drone use	Traditionally used resources	Limitations/main drawbacks
Hard to access & difficult to reach locations	Defect detection, Damage analysis, condition monitoring	Mobile scaffolding, harness equipment, mobile lifting equipment,	Laborious, high logistical efforts, time consuming, expensive
High rise building sites	Defect detection, structural integrity, vertical site conditions, building energy efficiency	Mobile scaffolding, cranes, elevation platforms, cherry pickers, telehandlers	Cost to install mobile scaffolding, logistics of bringing cranes/elevation platforms to site
Bridge construction	Assessment of deterioration,	Elevating platforms, underbridge units, cherry pickers, compact crawlers,	Inspectors walking across bridge decks, safety risks
Dams	Interior delamination detection of coating, cracking conditions	Mast boom lifts, cherry pickers, cranes, specialist equipment,	Technical difficulties, difficult access to bottom of dam, cause serious schedule disruptions
Roads and highways	Technical audits, Subsurface damage detection, displacement detection	Inspection by vehicle, inspection by motorcycle, walkthrough	Road closure, laborious,
Large construction	Cracking conditions, latent corrosion, Interior delamination detection of coating	Cranes, articulated boom lifts, cherry pickers, telehandlers, scissor lifts	Disturbance to ongoing works/trades, logistics of getting equipment to location through complex site

Industrial facilities	Surface defects, latent corrosion	Specially trained industrial climbers, specialist equipment, ultra-booms, scissor lifts	High personnel cost, limited specialists, considered hard and hazardous for human to inspect
Power plants & cooling towers	Cracks and leaks, pitting corrosion, tubular & pipe welds integrity,	high-capacity telehandlers, elevating platforms, X-ray systems, rejectors, electromagnetic testing, telescopic boom lifts	Units can cause disturbances, considered hard and hazardous for human to inspect
Wind turbines	Flows of electrical & mechanical installations, surface cracks, Leading-edge erosion, Delamination	Truck cranes, elevating platforms, cherry pickers, telescopic boom lifts	Dangerous, costly, inefficient, inspectors can only reach 28 cm inside turbines
Oil and Gas pipe	Welds integrity, fractures at joints, stresses	X-ray, rejectors, electromagnetic testing, ultrasonic transducer, high-capacity telehandlers.	Hazardous environment for human inspector, only specialised inspectors with proper training of environment. Inspection may require specialised suits.

2.4. Drone technology in construction

2.4.1. Defining drone technology

Drones are autonomous or remote-controlled unmanned aircrafts that are operated through wireless electronic gadgets, microprocessors, and sensors (Kumavat and Jain, 2019). They can be referred to as UAVs, UASs, RPAs (Mosly, 2017; Kumavat and Jain, 2019; Rodríguez *et al.*, 2021). According to the International Civil Aviation Organisation (ICAO), an RPAs is any aircraft that is intended for flight without an onboard pilot (ICAO, 2015). The South African Civil Aviation Authority (SACAA) refer to drones as RPAs operated from a reserved control station which excludes toy and model aircrafts (SACAA, 2021). However, the term RPAs is commonly used in the context of military and aviation regulations. These devices are normally fitted with numerous technologies for instance cameras, sensors, and navigation systems, allowing them to operate without immediate human involvement.

Particularly, a typical drone AI system interacts with the ground control station through short and long-range communication channels in real time (Ruiz *et al.*, 2021). In effect, drone technology can be described as an interaction between hardware components, microprocessor and sensor technologies, and software forming a complete system consisting of an aircraft, control station and data link (Ameli *et al.*, 2022). Generally, the mechanisms, configuration and drone speed differ based on their operation, weight, and application (Mohsan *et al.*, 2022). Hence, drones with different wing structures, engines and specifications have been developed. Apart from military drones that can be complex tools used for surveillance, reconnaissance and armed missions, drones for civilian use include three main categories: (1) fixed-wing drones which resemble traditional airplanes; (2) multirotor drones which feature multiple rotors for lift and control; and (3) hybrid drones which possess combined features of multirotor and fixed-wing drones for enhanced versatility (Mohsan *et al.*, 2022; Bayomi and Fernandez, 2023).

Essentially, drone technology refers to the design, development, and utilisation of UAVs with onboard computers programmed to autonomously follow a certain flight path or remotely operated by a pilot (Yıldızel and Calış, 2019). Drones are also equipped with various sensors, cameras, and other payloads, allowing them to capture and communicate data, perform tasks, and execute missions such as aerial photography, surveillance, mapping, and more (Choi *et al.*, 2023). Advances in drone technology have led to the development of sophisticated and versatile unmanned systems with capabilities for real-time data analysis and autonomous decision-making. Hence, drone technology has advanced significantly in recent years, enabling a wide range of applications across various industries (Bodecker and Wackwitz, 2017; Sreenath *et al.*, 2020).

2.4.2. SA's regulatory environment and the emergence of drone technology

The emergence of drone technology has significantly influenced and, in turn, been impacted by the highly regulated aviation environment. The increasing prevalence of drones across various applications, ranging from commercial to recreational activities has prompted regulatory authorities to create policies and regulations governing their operation (Henderson, 2022). Thus, the regulatory environment has a significant impact on how drones are adopted, integrated, and used responsibly in a variety of industries (Melo *et al.*, 2017; Henderson, 2022). For example, recreational use of drones in the United States was legislated in 2012 and in 2015 the increasing number of drones forced the Federal Aviation Administration (FAA) to mandate registration of all drones due to the innate threat of incidents and the lack of collision insurance (Mandourah and Hochmair, 2022, 2022). As drones share airspace with traditional aircraft, regulations work to facilitate the seamless integration of drones into existing air traffic management systems.

Furthermore, regulations provide operational guidelines for drone users, covering aspects such as permissible flight zones, daylight operation, and adherence to aviation standards (ICAO, 2015; Howard, Murashov and Branche, 2018). Many regulatory frameworks require drone operators to obtain licenses or certifications, ensuring that individuals have the necessary skills and knowledge to operate drones safely. According to Zwickle, Farber and Hamm, (2019), regulations pertaining to novel and developing technologies are predominantly grounded in ethical considerations, risk assessments, or prospective consequences. This is especially true when it comes to drones, and the possible harm they pose to people and manned aircrafts.

In SA, the regulatory framework for drone use is developed by the SACAA under Act 13, 2009 (Act No 13 of 2009). "*The Eighth Amendment of the Civil Aviation Regulations, Part 101: Remotely Piloted Aircraft Systems, was gazetted in May 2015 to oversee the safety and security of the drone industry in response to the rapidly increasing number of drones in the country*" (Mokoena *et al.*, 2023). These regulations are derived from the international civil aviation organisation (ICAO), a United Nations agency, which contains the standards and recommended practices for the global civil aviation including RPAS operation. Civil Aviation Technical standards (SA CATS 101) for drone flight contains compliance requirements for the safe operation of an RPAS (Nkamisa, Abrahams and Thukani, 2021; SACAA, 2021). The part 101 regulations encompass several drone operation approval and certification ranging from visual line-of-site (VLOS), where an operator must fly in line of sight of the drone; beyond visual line-of-sight (B-VLOS), where an operator can operate the drone out of sight through its camera; and restricted visual line-of-site (R-VLOS) which means the operator must not exceed a horizontal distance of 500 meters (SACAA, 2021).

On the other hand, there are certain regulatory rules and laws governing commercial drones' operations that must be followed prior to deployment (Mokoena et al, 2023). Around the world, there are numerous opposing viewpoints regarding the regulation of drones. A variety of viewpoints, including sociological, technical, and operational lenses, have been offered by various researchers (Zwickle, Farber and Hamm, 2019; Nkamisa, Abrahams and Thukani, 2021; Albeaino, Gheisari and Issa, 2022; Henderson, 2022; Mandourah and Hochmair, 2022; Mokoena *et al.*, 2022, 2023; Szóstak *et al.*, 2022)

2.4.3. General considerations about drone technology potential for construction industry

The current advancements and rapid evolution in technology have led to a widespread adoption of drones across various industries such as agriculture, mining, and construction (Charlesraj and Rakshith, 2020). Within the construction industry, these UAVs are revolutionising the manner in which construction projects are conceptualised and executed, from planning, surveying, and monitoring, offering efficiency, safety enhancements and cost savings (Bodecker and Wackwitz, 2017; Mahmood, 2020; Rao *et al.*, 2022).

Notably, the construction industry has significantly benefited from drone technology, particularly in aspects such as visual surveillance and project progress monitoring (Jacob-Loyola *et al.*, 2021). According to Sawant *et al*, (2021) drones possess the capability to capture numerous high-quality images and convert the data into three-dimensional models, thereby assisting construction professionals in tasks such as surveying, monitoring, and inspections. The existing literature indicates that the use of drones in site management can encompass a range of functions, including monitoring construction activities, conducting aerial photography and surveillance, performing visual inspections in difficult-to-access areas, conducting on-site safety inspections, detecting anomalies and defects, and facilitating communication with workers, among others (Zhou and Gheisari, 2018).

In view of that, Falorca and Lanzinha (2020) argue that traditional site surveying techniques are generally laborious and expensive, whereas drones streamline the process while capturing detailed images and generating accurate high quality 3D maps. To this effect, these aids in creating accurate topographical models, identifying potential geotechnical challenges, and optimising project designs (Álvares, Costa and Melo, 2018; Falorca and Lanzinha, 2020). As Guan, Zhu and Wang, (2022) suggests, drones fitted with high-resolution cameras and LiDAR technology are becoming instrumental for mapping and surveying on construction sites.

Furthermore, drones can provide a bird's-eye view of the construction site, enabling real-time project progress monitoring, swift identification of nonconformances, and a live comparison between as planned and actual timelines (Rey, de Melo and Costa, 2021). Additionally, high-quality images and videos captured during monitoring processes ensures remote monitoring and serve as comprehensive documentation tools for project stakeholders (Ashour *et al.*, 2016). Hence, the scaling up of the magnitude of data collected by drones from volumetric analysis to progress tracking empower project managers with insights that enable them to make informed strategic decisions (Martinez *et al*, 2021).

Withal, drones equipped with specialized sensors and cameras can efficiently carry out the various types of inspections such as quality control, safety, and environmental inspections (Aiyetan and Das, 2022). These capabilities are particularly valuable on complex projects, infrastructure such as bridges, towers, and roofs for routine maintenance inspections, where physical access requires specialised equipment. Thus, performing drone-based aerial inspections eliminate the need for costly and often risky physical inspections (Morgenthal *et al.*, 2019; Falorca and Lanzinha, 2020; Nordin *et al.*, 2022).

Likewise, safety is paramount in the construction industry, and drones contribute significantly to minimising on-site risks. As noted by Nooralishahi *et al.*, (2021) and Sudevan, Shukla and Karki, (2018) they can be deployed to inspect structures, monitor hazardous areas, and assess potential safety concerns without exposing workers to unnecessary dangers. As such, this 'location independency' approach to safety enhances overall construction project risk management, fostering a safer working environment (Ramos-Hurtado *et al.*, 2022).

Consequently, the application of drone technology within the construction industry has dramatically increased over the past ten years, along with the diversity of commercially available drones (Choi *et al.*, 2023). Robotic and automation technologies like drones give businesses in the built environment cutting-edge possibilities by offering remote monitoring, actuation, and predictive capabilities, thus enhancing operational intelligence (Albeaino, Gheisari and Franz, 2019). Nevertheless, the deployment of drones in construction site management can be described as a relatively new phenomenon, and industry players are currently learning about their potential uses in this regard (Kim and Irizarry, 2020).

2.4.4. Enablers and drivers of drone technology proliferation in construction

Understanding the diffusion of drone technology within the construction industry requires the appreciation of the interests of key role players in adopting the technology and the capacity within the industry to absorb and develop the technology (Kim and Irizarry, 2020; Guo and Wang, 2022). Similarly, one must focus on the strategic value of drones for key role players and discuss how the current status quo of the construction industry could be an incentive in the implementation of the technology. Second to that, attention must be paid to the supply side of drones within the country, focusing on how technological evolution may stimulate progress in the development of drone technology.

Although competition is often a major driver in technology adoption, willingness also depends in part on the organisational factors such as financial capacity (Steiber *et al.*, 2020). Generally, in the construction industry, certain factors play a crucial role in the widespread use and integration of technologies such as commercial drones. Below are three main factors extrapolated from extent literature that are seen as encapsulating enablers in driving proliferation of drone technology adoption within the construction industry.

Regulations which facilitate and promote drone economy

The regulatory landscape for commercial drone operations stands as a pivotal determinant influencing the rate at which key role players adopt drone technology (Duque, Seo and Wacker, 2018; Henderson, 2022; Mokoena *et al.*, 2022). Extant literature reveals that professionals acknowledge the benefits of drone utilisation but seek well-defined regulations governing when and where drones can be used. Moreover, there is a need for guidelines ensuring the safety and efficiency of drone operations and clarity on the criteria authorities use for issuing licenses or permits for commercial drone applications (Mokoena *et al,* 2022). To address these concerns, the development of regulatory frameworks with the aim to establish guidelines that facilitate the secure and business-friendly use of drones, which will in turn catalyse the acceptance of drone-aided functions within the construction industry is a necessity to drive proliferation (Yıldız, Kıvrak and Arslan, 2021).

With the exponential drone market growth in recent years, it has become increasingly evident that drones play a pivotal role in the digital economy. As a response to this trend, regulatory bodies in several countries such as the EU, Ireland and USA have opted to loosen restrictions on commercial drone operations while simultaneously providing guidelines and training (Mandourah and Hochmair, 2022; Gain, 2023). These regulatory adjustments have unlocked new possibilities by relaxing rules on factors such as maximum altitude and minimum distance from non-participating individuals and structures, enabling drone flight flexibility (Mandourah and Hochmair, 2022). Despite these advancements, regulations still impose constraints on autonomous flights and beyond visual line of sight (B-VLOS) operations. However, once these restrictions are eased, the potential to introduce additional applications of drone technology in the construction industry is nascent. For instance, drones operating beyond visual line of sight could engage in B-VLOS inspections and monitoring on complex construction sites (Szóstak *et al.*, 2022).

Technological evolution

Apart from driving the pace of regulatory change, technological evolution in hardware solutions, software and data processing coupled with decreasing costs, are poised to expand the range of potential drone applications, and stimulate increased investment (Ruiz *et al.*, 2021; Bayomi and Fernandez, 2023). Particularly, continuous enhancements in components that significantly influence their efficiency, safety, and reliability are expected to be key drivers for the growth of drone-powered solutions in the immediate future (Bayomi and Fernandez, 2023; Ameli *et al*, 2022). For example, Choi *et al*, (2023) suggests that ongoing efforts in developing hydrogen fuel cells and showcase a more efficient alternative to the current electric batteries, promising reduced weight and increased flight time.

According to Macrina *et al.*, (2020) and York, Al-Bayati and Al-Shabbani, (2020), this technological evolution coupled with wireless power transfer techniques signifies a significant impact on the capabilities of drones. Furthermore, drone manufacturers are actively working on implementing autonomous collision avoidance systems, which involve processing data from the drone's sensors to prevent collisions or enable automatic take-off and landing (Freimuth and König, 2018; González-deSantos *et al.*, 2020; Thibbotuwawa *et al.*, 2020). While this technology is currently deployed in a limited number of devices, continuous improvement and refinement are ongoing trends in this field.

Operational efficiency, enhanced data quality and accessibility

Continued advancements in data analytics and processing software enable construction professionals to derive meaningful insights from drone-captured data (Bayomi and

Fernandez, 2023). However, to deliver substantial insights and recommendations, it is imperative to present this information quickly, comprehensively, and in an easily understandable manner across various devices, whether mobile or desktop, accessible anytime and anywhere (Israr *et al.*, 2021; Choi *et al.*, 2023). Therefore, data accessibility is a pivotal driver propelling the continued adoption of drone technologies in operational processes. Notably, this emphasis on data accessibility aligns with the broader trend of simplifying and automating drone usage. On the other hand, several scholars such as York, Al-Bayati and Al-Shabbani, (2020) suggest that the ability of drones to gather high quality data at a lower cost will drive increased demand for functions including photogrammetry and geospatial analyses.

Operational efficiency, high-quality data collection and analysis, and increased accessibility stand out as pivotal driving forces behind the advancement of drone technology (Asadi *et al.*, 2020; Albeaino and Gheisari, 2021; Nwaogu *et al.*, 2023). Drones are increasingly recognised for their ability to streamline various operations, elevate the accuracy of data collection, and enhance the accessibility of information (Perez, Zech and Donald, 2015). These factors contribute to the widespread adoption and integration of drone technology across diverse industries including the construction industry. In essence, the synergy of operational efficiency, improved data quality, and increased accessibility positions drone technology as a transformative tool for various construction related applications (Yi and Sutrisna, 2021).

2.4.5. Application of drone technology in construction project management

The implementation of drone technology in construction could be said to emanate from the drivers and associated benefits in the ability of drones to perform tasks efficiently and safely, as well as their capabilities in accessing unreachable of unsafe areas (Albeaino, Gheisari and Franz, 2019; Albeaino and Gheisari, 2021). Furthermore, developments in RPAs, regulation updates, enhanced navigation features, multiple onboard sensors and autonomous flight features have led to their integration into construction projects (Ding *et al.*, 2017; Nooralishahi *et al.*, 2021; Ruiz *et al.*, 2021). Drone technology can be implemented in construction projects to aid multiple construction related tasks throughout the project life cycle (Álvares, Costa and Melo, 2018). For instance, Eiris *et al.*, (2020) investigated the use of drones for building inspections while Martinez *et al*., (2020) investigated the implementation of drone technology for construction progress monitoring. Accordingly, common pre-construction applications of drone technology include site surveying, site mapping and site planning, which entails the collection of geospatial and temporal site data (Hammad *et al.*, 2021; K. Chen *et al.*, 2021; Mahajan, 2021). The implementation of drones for these tasks has been noted as an alternative to the conventional surveying methods that usually rely on total stations, GPSs, LiDAR devices and terrestrial laser sensors.

However, drone technology is mostly implemented during the construction phase of projects (Mahajan, 2021). Extent literature shows that implementing drone technology during this stage can affect multiple processes such as quality control of construction works (Devers, 2019; Rachmawati and Kim, 2022), project monitoring (Martinez *et al.*, 2020), post construction inspections (Asnafi and Dastgheibifard, 2018), as well as site security surveillance (Melo *et al.*, 2017; Martinez *et al.*, 2021). On the other hand, post construction applications include inspection purposes in building maintenance and post disaster assessments (York, Al-Bayati and Al-Shabbani, 2020; Razafimahazo *et al.*, 2021). Furthermore, Mutis and Romero, (2019), (Dias, Flores-Colen and Silva, (2021), and Katsigiannis *et al.*, (2023) among others note that drones can be deployed as an efficient alternative to conventional operational and maintenance practice in areas such as façade and roof inspections.

Evidently, drone technology can be implemented in varying construction projects including residential, commercial, civil infrastructure projects and industrial projects, before, during and post construction. Undeniably, the application of drone technology in construction project management has become increasingly prevalent, revolutionising traditional practices and offering various benefits. Table 2.6 below depicts drone technology application areas in construction as derived from extant literature.

Table 2.6: Drone technology application in construction projects

Application	**Description**	**Building lifecycle phase**	**References**
Site Evaluation	Aerial view of the site that lets project managers, architects, and engineers check out the conditions, ease of access, closeness to transportation networks, and nearby infrastructure to figure out any entry requirements, restrictions, or problems.	Design Phase: Conceptualisation, viability assessments for design precision.	Choi et al, 2023; Hammad et al, 2021; Jiang et al, 2020; Tkac and Masaros, 2019; Albeaino nd Gheisari, 2021
Site Surveying and Mapping	Evaluations of the site's geography, current buildings, boundaries, distances, elevations, and contours, which makes it easier to make accurate 3D models and do math and georeferencing.	Construction phase: Site clearance and preparations to break ground.	Yildizel and Calis, 2019; Sawant et al, 2021; Lee et al, 2022; Tkac and Masaros, 2019; Albeaino nd Gheisari, 2021
Earthwork and grading monitoring	Volume calculations with cut-and-fill volume data, height difference review, cut and fill analysis and slope monitoring,	Construction phase: Site clearance and levelling involving cart-away.	Choi et al, 2023; Tkac and Masaros, 2019; Mahajan, 2021; Albeaino and Gheisari, 2021
Construction site inspections	Accurate identification of construction or technical issues. Comparison of as built structure to original plan.	Construction phase: Quality control, environmental impact assessment, specialised inspections.	Sawant et al, 2021; Martinez et al, 2021; Tkac and Masaros, 2019; Albeaino nd Gheisari, 2021; Nooralishahi et al, 2021
Progress Monitoring	Real-time tracking of site development. Recording, measurement, and communication of the work completed on-site.	Construction phase: regular update of progress to key stakeholders.	Sawant et al, 2021 Jacob-Layola et al, 2021; Dastgheibifard and Asnafi, 2018;

Material Tracking and monitoring	Monitoring and tracking location and orientation of construction equipment.	Construction phase: Material inventory, security and housekeeping.	Sawant et al, 2021; Wong et al, 2020; Zhang et al, 2018
Occupational Health and Safety inspection	Direct observation of workers' safety compliance from various angles. Visual inspection of the use of PPE. Monitoring ongoing activities for unsafe situations/locations.	Construction phase: Adherence to OSHA, safety culture, risk management.	Alizadehsalehi et al, 2020; kim et al, 2020; Martinez et al, 2020; Jordan et al, 2018; Melo et al, 2017
Building inspection	Suitability of physical and functional conditions structures/ buildings	Operation & Maintenance: Detection	Tan et al, 2021; Grosso et al, 2020; Ruiz et al, 2021; Albeaino and Gheisari, 2021; Nooralishahi et al, 2021
Infrastructure inspection	Routine inspections of infrastructure that are traditionally difficult to inspect such as bridges, highways, dams. Eliminates the need for access equipment.	Operation & Maintenance: Detection	Harinarrain and Naicker, 2019; Duque et al, 2018; Kumavat and Jain, 2019; Kim and Irizarry, 2020; Ameli et al, 2022

2.5. Drone-aided inspections on construction sites

2.5.1. Overview of drone-aided construction site inspections.

Drone-aided inspections entails the use of drone (UAVs, UASs, RPAs) and the various technologies that these vehicles, systems or aircrafts can be fitted with to aid in the conduct and optimisation of an inspection process (Elghaish *et al.*, 2021). According to Mahmood, (2020), drone technology is used to increase productivity of the inspection personnel, for ease of access to difficult to reach areas and improve the quality of the inspection process. The ubiquity of drone technology creates real-time collection and communication of inspection data, providing entire teams with instant, remote access to inspection processes (Guan, Zhu and Wang, 2022). Thus, creating a shift from periodic inspections to real time monitoring. Guan, Zhu and Wang, (2022) posits that it is a vastly more precise, efficient, and faster method than traditional inspection methods. Consequently, it can be interpreted as a more accurate, affordable, and less labour intensive way for inspection specialists to inspect, visualise and analyse elements within the scope of the inspection.

By now, it is clear that drone technology provides a myriad of positive applications in construction process control. However, Martinez *et al*, (2021) argue that the most positive drone-based process control measures are realised when implemented for inspection and progress monitoring purposes. Notably, most drone-aided inspections use visual-based techniques such as photogrammetry, LiDAR and thermography (Falorca and Lanzinha, 2020; Kim and Irizarry, 2020). There are, however, a relatively small number of UAVs that can perform close-contact NDT inspections (Nordin *et al.*, 2022). For contractors, the frequent acquisition of drone data enables rapid integration into projects and precise real-time tracking of construction site progress. This enables the construction project management team to better manage their time and resources while averting unforeseen challenges and delays (Munawar *et al.*, 2022).

Freimuth and König, (2018), Mahami *et al.*, (2019) and Mahmood, (2020) suggest that project teams may find drone-aided construction site inspections to be a useful resource in confirming that the project's objectives are being accomplished. In this regard, a drone operator with formal training may utilize the drone to identify any construction or technical concerns on site resulting in major cost savings during construction execution (Sawant *et al.*, 2021).

Furthermore, drones may also be a safer alternative since they care capable of reaching dangerous areas on the construction site when assessing damages (Li and Liu, 2019; Tan *et al.*, 2021). Drones may also be used to create comprehensive 3D models of ongoing construction projects (Grosso *et al.*, 2020; Ruiz *et al.*, 2021), fly over a construction site to assess how closely it follows the plan or model, inspect what is happening on the roof of a high-rise building as it is being built, etc. (Fan and Saadeghvaziri, 2019). Likewise, site inspections may be carried out more often and more efficiently across the entire site with increased safety, less labour intensive data collection, improved data quality, and reduced cost (Falorca, Miraldes and Lanzinha, 2021a; Munawar *et al.*, 2022). Consequently, this enables project managers to make informed operational decisions from the high-quality inspection data collected.

Generally, a typical drone-aided inspection procedure entails the following steps (Freimuth and König, 2018; Ciampa, De Vito and Rosaria Pecce, 2019; Ndegwa, 2019; Rodríguez *et al.*, 2021; Szóstak *et al.*, 2022)

1. On the drone technology app, the pilot drafts the flight plan, defining the site inspection parameters, which may be done either on-site or in the office.
2. The pilot then launches and controls the drone using the controller or a mobile phone app once the plan is prepared and everything is verified to be in order.
3. Depending on the sensors and the purpose of the inspection, the drone automatically follows the flight route while taking pictures and gathering any other data.
4. Once the inspection parameters have been surveyed, the drone then autonomously lands in accordance with the program.
5. Drone AI used for automatic detection of defects also sends the data to the mobile device or any other designated place in real-time.

Additionally, a variety of imaging and analysis software are available that enable the creation of photogrammetric 3D models, point clouds and 2D orthomosaics, and the generation of several useful reports for progress monitoring, tendering, insurance evaluations, marketing, etc (Álvares, Costa and Melo, 2018; Morgenthal *et al.*, 2019; Ruiz *et al.*, 2021).

2.5.2. Drone-aided inspections: A shift from quality control to complete quality assurance

Due to their versatility, data processing and analytics capabilities, drones have emerged as invaluable tools, facilitating a shift from traditional quality control practices to more proactive and comprehensive quality assurance approaches (Hammad *et al.*, 2021). This transition not only enhances efficiency but also brings about a future-focused paradigm shift in how inspections are conducted. Morgenthal *et al*., (2019) are of the opinion that as drone technology evolves, the synergy between drone advancements and quality assurance practices will likely define the next era of inspections across the construction industry.

On the other hand, Lu *et al.*, (202) argue that there is a need to manage quality in a way that addresses both patent and latent defects that could appear during product use. As such, they note that the alterations needed in design practices to establish a formal quality management system, ensuring quality assurance through effective quality control, may not demand significant changes. Instead, slight adjustments to existing practices through automation and robotics technology such as drone technology can ensure continuous improvement, assurance, and the necessary control measures to enhance overall quality. Thus, the shift towards proactive quality management would aim to identify and address potential challenges early on, guaranteeing enduring quality from conception throughout the entire lifespan of the building (Ribah and Singh, 2023).

In order to move from periodic inspections to real time monitoring, robotic systems are being investigated more and more as an improvement to current inspection processes. According to Jeong *et al.*, (2022), Utilising drones as airborne sensor systems can greatly enhance the quality and efficiency of monitoring and inspecting infrastructure development. This technological advancement can elevate the standards and uniformity of projects to a new level. Thus, the integration of drone technology marks a pivotal shift from conventional quality control methodologies to a more holistic approach of complete quality assurance by offering a comprehensive and proactive strategy for ensuring quality across all facets of the project (Rey, de Melo and Costa, 2021; Jeong *et al.*, 2022; Hussamadin, Jansson and Mukkavaara, 2023). Furthermore, Halder *et al.*, (2023), argue that drone-aided inspections facilitate a proactive approach to early detection of potential concerns which aligns seamlessly with the broader goal of comprehensive quality assurance. Essentially, as technology continues to evolve, the integration of drones in inspection practices will likely redefine the standards for complete quality assurance in the foreseeable future.

2.5.3. Drone-aided inspection processes on construction sites.

The implementation of drone technology on construction sites follows a certain process that involves particular role players. Commonly, a typical drone-based deployment process often involves of three major steps: "*pre-flight, flight, and post-flight"* (Kim and Irizarry, 2020). The pre-flight mission step entails a flight mission planning and pre-data collection meeting on site, control station setup, as well as equipment setup and testing (SACAA, 2021). Furthermore, the primary goal of the pre-flight step is flight planning, which entails deciding on the inspection area, choosing the location for take-off and landing, as well as creating a flight mission plan (Freimuth and König, 2018; Kim and Irizarry, 2020). On the other hand, the primary duties during the flight phase encompasses gathering inspection data at the specified locations of the site while adhering to the flight mission created during the pre-flight and on-site meeting. After the drone has landed, the equipment is disassembled, and data is then processed and analysed post flight for decision making and documentation (Henderson, 2022).

Essentially, the importance of the site meeting is so that key role players can determine flight mission specifics such as the inspection point of interest, take-off and landing sites, potential obstacles and the ground control station. Therefore, a thorough flight mission plan should come out of the discussion. The ground control station (GCS) houses the necessary equipment for a successful drone-aided inspection event, including the drone manual navigation control system, operators' communication system, and backup batteries (Palacios *et al.*, 2018; SACAA, 2021).

Also, after setting up the GCS, the pilot and his visual observation assistants perform final checks to ensure the drone is ready for the flight mission (Henderson, 2022). Kim and Irizarray, (2020) state that it is important for the pilot and visual observers to keep direct communication through two-way radio to avoid accidents, lost connections, and non-compliance with critical parameters essential for a safe flight mission. Visual observers are responsible for visually observing flying conditions and the aircraft position during flight so that the pilot may focus on flight control and inspection of critical areas (Falorca and Lanzinha, 2020). When the pilot determines that a mission is complete, he or she should give the visual observer a signal to prepare for landing. The observer prepares the landing site and communicates a signal of approval for landing to the pilot who then verifies the camera view of the landing site and proceeds to dock.

The amount of time required for data processing is determined by the number of images gathered, the resolution of the photos, and the capabilities of the software program used (Howard, Murashov and Branche, 2018). Data can be downloaded directly to a local storage device or moved to a cloud-based common data environment (CDE) by the project management team (Sawhney, Riley and Irizarry, 2020). Furthermore, once the data has been processed, it can be analysed using certain inspection parameters depending on the status of construction works. Thereafter, project stakeholders can use the inspection data to create a photogrammetric 3D model, discuss, assess, and apply the results to their quality control strategies (Ashour *et al.*, 2016; Irizarry and Costa, 2016; Yıldız, Kıvrak and Arslan, 2021). The list below summarises the important responsibilities of the key role payers during the deployment of drone technology for drone-aided inspections of construction works.

Drone pilot

- Performs pre-flight checks to ensure the drone is airworthy as per SA-CATS101.
- Perform a job safety assessment (JSA) to ensure practicable measures are followed to mitigate hazards to property and risks to persons.
- Complete a drone mission checklist which contains all procedures necessary for a safe drone flight mission.

- Turns on and pilot the drone safely for reconnaissance flight along the inspection pathway according to RPAs manual.
- Must specify speed, altitude limit, maximum height of inspection, windspeed, maximum rotation speed during take-off and flight control (Outay, Mengash and Adnan, 2020).

Construction Project Management team

- Establishes pending list of works to be inspected.
- Designs the path/paths along which the reconnaissance is to be performed.
- Inform drone operator of the flight path through flight map.
- Assess, analyse, and monitors defects and risks based on the relayed inspection data (Zainudin, 2018).

Construction site management team.

- Prepare a work schedule clearly outlining specific activities to be executed during the inspection process.
- Define inspection area to be observed taking into account all physical objects on site based on technical knowledge and experience.
- Communicate with site personnel about the use of drone on the site and risks involved to reduce worker distraction due to the presence of a drone.
- Analyse the scale of risks and defects based on acquired drone inspection report (Moore *et al.*, 2018).

Inspector responsibilities

- Assess digital inspection checklist during flight mission
- Utilise images and data collected from inspection to detect any defects, risks and hazards (Nooralishahi *et al.*, 2021).

Undoubtably, it is critical to ascertain these responsibilities in order to understand the context specific responsibilities that the key role players will assume during the drone-aided inspection event. Hence, these responsibilities will enable the comprehension of how and where certain challenges to the deployment of drones on construction sites arise (Moore *et al.*, 2018; Zainudin, 2018; Alsamarraiea *et al.*, 2022).

2.5.4. Drone types for construction site inspections

There are a variety of drones that can be used for inspection purposes in the construction industry. However, there are three categories which all drones belong to, based on their mechanical composition: rotary-wing drones (commonly known as multirotor or quadcopter UAVs), fixed wing drones and the tilt-wing, which is hybrid version (Ruiz *et al.*, 2021).

Multirotor UAVs are controlled by adjusting rotor thrust and torque, allowing them to hover in a fixed position and manoeuvre swiftly in any direction, making them more agile than fixed-wing UAVs. They can take off without a runway and may feature four, six, or eight rotors, with a higher number ensuring continued flight even if one engine fails. However, multirotor drones generally have slower maximum speeds and shorter flight times compared to fixed-wing drones. On the other hand, fixed-wing drones resemble airplanes in structure, offer longer flight durations at higher speeds, making them suitable for surveying larger areas (Hu and Assaad, 2023). They can carry heavier payloads over longer distances with less power consumption, enabling the use of larger and more advanced sensors and cameras.

Unlike multirotor drones, fixed-wing drones cannot hover and require constant forward motion. Additionally, they need a runway or launcher for take-off and landing, limiting their suitability for inspection operations in confined areas. The hybrid model, tilt-wing, combines features of both types. It can hover as needed and transition to faster fixed-wing flight, offering advantages like longer flight distances without requiring a runway with the ability to hover. While the number of tilt-wing drones in the market is currently limited, companies, including Amazon, are actively developing new models, particularly for transport applications (Shakhatreh *et al.*, 2019; Zollini *et al.*, 2020).

The selection of an appropriate drone for an inspection application is contingent upon various factors, including the size of the area to be covered, the necessary payload capacity, and the operational environment (Benos *et al.*, 2023). Each type of drone possesses its own set of advantages and disadvantages. For example, rotating-wing drones are better suited for operations in restrained locations and close-range inspections, whereas fixed-wing drones are best for swiftly covering wide regions (Nex *et al.*, 2022; Hu and Assaad, 2023). While hybrid drones can be more expensive and sophisticated than fixed-wing or rotary-wing drones, they provide a more flexible and adaptable option. While table 2.7 below outlines the drone categories with their unique advantages and disadvantages, table 2.8 details drone models that are best suited for construction site inspections. The table outlines the specifications of each model including the maxim flight times.

From the drone categories outlined in table 2,7, rotary-wing/multi-rotor drones (quadcopters, hexacopters) are regarded as the best option for drone-based inspections in construction due to airframes and avionics (Mahmood, 2020; Mohsan *et al.*, 2022). However, when choosing a drone model for inspection purposes key considerations include the intended area to be covered, mapping resolution, processing requirements, and available payload capacity. For example, smaller drones usually carry lower-resolution cameras due to payload capacity whereas larger cameras that offer higher resolution are heavier and higher resolution imagery increases photogrammetric processing considerably (Bayomi and Fernandez, 2023).

Therefore, achieving a balance between resolution, payload capacity, and area coverage is crucial. For this reason, DJI is widely recognised as a leading choice for construction inspections because of its advanced technical features. It offers both fixed-camera drones for easy use and customisable gimbal and swappable payload options for greater flexibility in capturing visual data tailored to specific inspection needs. (Molina, Huang and Jiang, 2023).

Table 2.7: Overview of drone types and their applicability for construction site inspections

Type of drone	applicability	Advantages	Disadvantages
Rotary-wing (3,4,6,8 rotors)	Inspections & monitoring of all types of construction sites	Simple to operate with Vertical take-off and landing. Easily accessible & relatively less expensive. Well-suited for close range inspections. Excellent manoeuvrability. Suitable for congested construction sites.	Limited flight times <25 mins. Structural composition may affect quality and stability. Less suitable for large scale inspections. Susceptible to wind disturbances.
Fixed-wing	Efficient for large scale aerial inspections.	Can perform inspection in difficult weather. Longer flight time, higher speed, and endurance. Stable in windy conditions due to aerodynamic design. Can carry heavier high-resolution cameras. Provide very detailed aerial data.	Pilot’s expertise needs. Limitations in close-range inspections & manoeuvrability & hover abilities. Requires runway/open area for TOL Relatively expensive.
Tilt-wing (hybrid)	Combined features and capabilities.	Highly detailed data collection. Vertical take-off and landing capabilities. Longer flight time, higher speed, and endurance. Well-suited for close range inspections. Excellent manoeuvrability and stability.	Very complex to operate. Certain expertise and specific training required. Very expensive.

References: (Duque, Seo and Wacker, 2018; Shakhatreh *et al.*, 2019; Zollini *et al.*, 2020; Hammad *et al.*, 2021; Mohsan *et al.*, 2022; Nex *et al.*, 2022; Benos *et al.*, 2023; Choi *et al.*, 2023; Hu and Assaad, 2023)

Table 2.8: Best standard drone models for construction site inspections

Type	Model	Best inspection use case	Max Weight	Max Payload	Endurance (flight time)	Range (AMSL)	Transmission distance
Multirotor Quadcopter	DJI Matrice 300 RTK	Versatility in payload compatibility offers high-quality cameras with excellent zoom capabilities (Seo, Duque and Wacker, 2018).	6.3kg	2.7kg	55 minutes	7000m	15km
Multirotor Quadcopter	DJI Phantom 4 Pro	Best inspection drone for high-rise buildings and roof inspections. Surface crack detection (e.g., Corrosion, delamination) (Ameli *et al.*, 2022)	1.39kg	0.8kg	30 minutes	6000m	7Km
Multirotor **Hexacopter**	Yuncee H520	Most suitable for facade inspections with cinematic and broadcast-ready imaging (Golizadeh, Hosseini, Edwards, *et al.*, 2019b).	1.65kg	0.8kg	25 minutes	6000m	3.5km – 7km
Multirotor **Quadcopter**	Elios 3	Collision-tolerant capabilities makes is ideal for navigating confined, hard to reach internal spaces (Yıldız *et al.*, 2021).	2.35kg	0.6kg	12.5 minutes	3000m	500m

2.5.5. Benefits of drone-aided construction site inspections

Summarising the benefits identified through the analysis of extent literature, it can be concluded that they primarily involve time and cost reduction, increased accessibility, and the broadening of interoperability for various stakeholders in the sector. This, in turn, leads to greater effectiveness in conducting construction site inspections (Albeaino and Gheisari, 2021). Traditionally, inspections on construction sites have required significant labour and time. The advent of inspection drones has revolutionised this process, enabling project managers and inspectors to perform more comprehensive and efficient site assessments. Tkáč and Mésároš, (2019) outline costs, quality, time and safety as main reasons drone-aided inspections are considered as an alternative solution to traditional inspections.

Furthermore, recent advancements in sensor technology and onboard processing have unlocked focused aerial data collection capabilities suited to the multi-dimensional information requirements of quality assessments in construction site inspections (Dupont *et al.*, 2017). Currently, a variety of instrument payloads such as LiDAR and multispectral sensors are carried by drones to map, measure, assess and monitor the built environment (Shakhatreh *et al.*, 2019; Bayomi and Fernandez, 2023). This makes it easier to generate digital surfaces and precisely model 3D objects for the analysis of quality variables related to defects and nonconformances. Moreover, drones provide flexible and scalable platforms for seamlessly integrating custom sensor payloads required for a variety of infrastructure inspection tasks. The ability to swap these sensors between missions allows drones to accommodate diverse data capture requirements enabling real-time analytics during flights (Kazaz *et al.*, 2021).

Table 2.9: Summary of construction inspections benefits

Variables	**Advantages**	**References**
Increased accessibility and safety	• Increased efficiency as no access equipment is required. • Improves accessibility to confined/dangerous to reach spaces • Safer construction site risk avoidance procedures. • Provides a broader view of the workplace for construction crews. • Discovery of potential safety risks before they cause fatalities.	(Falorca and Lanzinha, 2020)
Less labour-intensive data collection and processing	• Inspection time is reduced since several tasks can be completed at once. • Reduced time spent on manual data collection, leading to simplified inspection phases. • Simplicity in the standardization of data to decrease variability. • High-definition imagery along with a replicable inspection pattern/process. • High mobility in data acquisition and the ability to fly at different heights.	(Duque, Seo and Wacker, 2018; Sreenath *et al.*, 2020; Yıldız *et al.*, 2021)
Cost & time savings	• Reduced cost of aerial inspection services. • Simplification of construction inspection activities leads to saving costs and time on data collection and inspection time.	(Zhou and Gheisari, 2018; Albeaino and Gheisari, 2021; Elmokadem and Savkin, 2021)

2.5.6. Challenges, limitations, and uncertainties of drone-aided site inspections

With drone technology continually advancing, there is little doubt that the value of drones in the construction sector will continue to rise. However, there are several challenges with using drones that arise throughout the construction industry which should be explored and addressed. The primary challenge noted in literature is cantered on regulations pertaining to the use of drones (Nielsen, 2017; Li and Liu, 2019; Outay, Mengash and Adnan, 2020; Sibanda *et al.*, 2021). Furthermore, operating a drone requires a competent professional since it may be a challenging task. Therefore, skilled operators are essential for the usage of drones in construction (Golizadeh, Hosseini, Edwards, *et al.*, 2019b; Mahajan, 2021; Mohsan *et al.*, 2022). Moreover, flight reliability is heavily dependent on weather conditions (Melo *et al.*, 2017; Falorca, Miraldes and Lanzinha, 2021b). Studies such as (Mahajan, 2021; Mohsan *et al.*, 2022) note the negative effects of strong winds on flight paths due to impaired navigation system. Therefore, to assure flight reliability and hence optimal efficiency, a robust algorithm that can handle a variety of circumstances must be devised (Rachmawati and Kim, 2022).

Likewise, Falorca and Lanzinha, (2020) found that drones that are in flight might distract construction personnel, which could compromise their safety. On the other hand, (Ciampa *et al*., 2019; Ruiz *et al*., 2021; York *et al*., 2020) discovered a major limitation with drone power capacity, which restricted the flight mission to 20-30 minutes with a recharge period of an hour. Accordingly, extant literature reviewed notes the following challenges organized in figure 2.3 below as hindering optimal deployment of drone technology for drone-aided inspections on construction sites. Addressing these challenges involves a combination of technological advancements, regulatory frameworks, training programs, and effective communication strategies. As the technology evolves and stakeholders collaborate, many of these challenges can be mitigated, unlocking the full potential of drone-based construction site inspections (Alsamarraiea *et al.*, 2022).

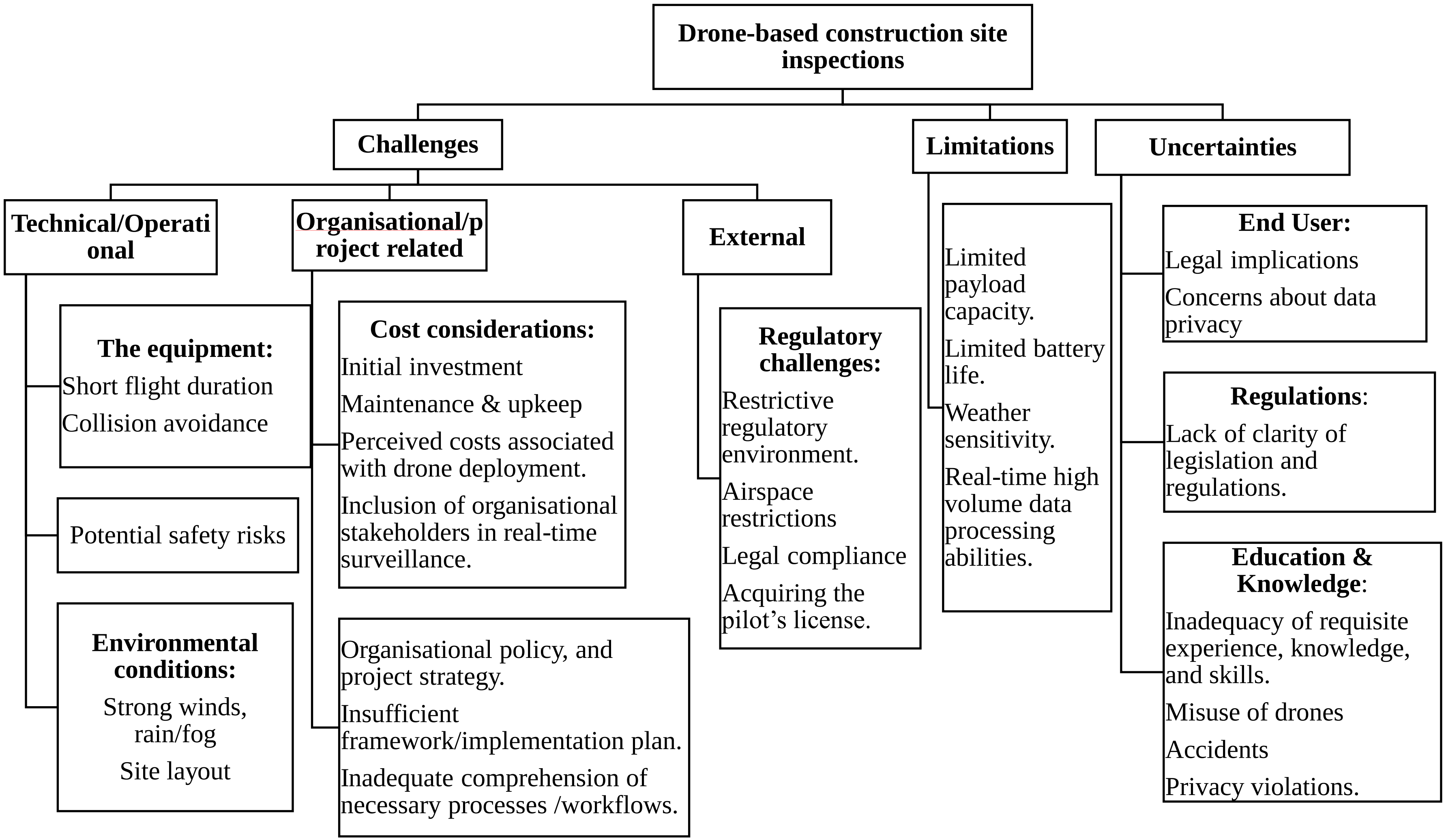

Figure 2 3: Challenges and uncertainties of drone use for inspections (adapted from Golizadeh et al., 2019 and Liang et al., 2023)

Therefore, it is essential to explore these foreseen challenges through a drone application-based research design so as to obtain substantial evidence with an emphasis on South Africa. Specifically, those challenges that hinder optimal adoption of drone technology for enhanced construction site inspections. Hence, the next section discusses concepts and relevant theories that would aid the researcher in achieving the aim of the research which is to explore these challenges empirically.

2.6. Theoretical Framework

A conceptual framework serves as a logically organised depiction of relationships, variables, and concepts that establish the foundation for constructing a methodical approach (theoretical framework) to elucidate a given phenomenon (Hennink, Hutter and Bailey, 2020). It facilitates the development of cause-and-effect connections among variables, thereby enabling the dependable prediction of facts (Saunders *et al.*, 2016; Nowell and Albrecht, 2019). Through a thorough examination of the existing literature, important research concepts have been clearly defined and the relationships between these concepts were proposed. Essentially, a theoretical framework affords the researcher guidance in interpreting, explaining and generalising research findings convincingly.

2.6.1. Relevant Theories from Extant Literature

Relevant theories evident in explored literature that predict and explain adoption behaviour include Roggers'(2003) Diffusion of innovation theory (DOI) (Alaloul et al., 2020); Ajzen, (1991) Theory of planned behaviour(TPB) (Al Nasseri et al., 2016; Charlesraj and Rakshith, 2020; Golizadeh et al., 2019a; Nyamazana and Ozumba, 2017); Unified theory of technology acceptance and use (UTAUT) (Ozumba et al., 2019); General system s theory (GST) (Nyamazana, 2019; Olanipekun and Sutrisna, 2021; Razafimahazo et al., 2021; Safapour et al., 2020); Technology-Organisation-Environment (TOE) framework (Al Nasseri et al., 2016; Henderson, 2022; Jere and Ngidi, 2020; Petrova et al., 2021; York et al., 2020).

From the above-mentioned theories, DOI purports perceived characteristics of a technology influence adoption rate (Rogers, 2003; Perkins, 2011). Perceived attributes of an innovation as key determinants of the rate of innovation enables understanding of how members of a social system can adopt a technology (Alaloul *et al.*, 2020). On the other hand, TPB suggest behaviour as a basis for salient information or beliefs relevant to behaviour as a basis for reasoning (Iyamu, 2021). In that regard, the theory puts forward a three-variable argument stating that attitudes influence intentions and in turn intentions influence behaviour (Charlesraj and Rakshith, 2020). Conversely, UTAUT is a comprehensive synthesis of previous theories on technology acceptance including TAM (Venkatesh *et al.*, 2016). The UTAUT enhances cumulative theory by incorporating the collective explanatory capacity of individual models and significant moderating influences, while retaining a parsimonious structure (Goger and Bisenberger, 2020). GST is a holistic discipline that provides a framework for understanding the interconnection within organized or complex structures (Von Bertalanffy, 1972; Hofkirchner, 2019). Lastly, TOE explains the influence of technological context, organisational context, and environmental context on the process of technological innovations adoption and implementation within organisations (Chiu, Chen and Chen, 2017; Jere and Ngidi, 2020; Picoto, Crespo and Carvalho, 2021).

2.6.2. Relevant Constructs

Perceived Attributes of innovations

Within his DOI theory, Rogers (2003) identifies five key determinants of innovation adoption (table 2.10) that enable us to understand of how members of a social system can adopt and implement a technology through perception. Below are brief definitions and descriptions of these perceived attributes.

Table 2.10: Determinants of innovation adoption (Rogers, 2003; Leunga et al., 2015)

Relative advantage	The degree to which a technology is perceived as an important catalyst to priorconditions. Important factors in measuring relative advantage include economic, social prestige, convenience, and satisfaction.
Compatibility	The degree to which a technology is reconcilable with the existing values of a social system, past experiences and needs of adopters. A technology that is inconsistent with values of

	existing systems is adopted at a slower rate than a technology compatible with the system.
Complexity	The perceived difficulty of understanding and use of technology. More complex ideas are diffused at a slower rate.
Trialability	The flexibility of a technology to experiment with within certain bounds. Ideas with visible instalments are diffused at a more rapid rate than invisibleinnovations.
Observability	The degree of visibility of results from using the technology. Other individualsare more likely to adopt a technology if the results of its use are visible. Visibility stimulates peer discussion.

Furthermore, within the diffusion process, information exchange between the source and recipient/s occurs through specialised communication channels over a perennial period (until a time of discontinuance) (Rogers, 2003).

Facilitating conditions

Facilitating conditions are defined as an individual's perceptions of the availability in organisational resources and technical infrastructure in implementing a technology (Venkatesh *et al.*, 2016). This construct encapsulates aspects of an organisational environment that have been developed to eliminate barriers to use of the technology, industry structure and external service provision (Ens, Stein and Blegind Jensen, 2018).

2.6.3. Conceptualisation of relevant theories for framework development

In the previous section, relevant theories and constructs are discussed. Hence, this section describes theories that can aid the researcher in designing a conceptual framework. The basis for selecting these theories is their parsimonious ability that when merged, can enable a conceptual lens through which the researcher can view the research problem and therefore achieve the research objectives (Chiu, Chen and Chen, 2017; Iyamu, 2021). Concepts and variables that guide the development of the conceptual framework have been identified in extent literature. Therefore, a conceptualisation of CSM execution of the inspection processes within SM through leveraging drone technology for inspections of construction works. Against this backdrop, theories that will be used to formulate the conceptual framework are DOI by Rogers, (2003) and TOE Tornatzky and Fleischer, (1990). It is worth noting that other theories such as UTAUT, TPB, etc. are more associated with initial adoption whereas DOI and TOE extends to continued use of a technological innovation (Chiu, Chen and Chen, 2017; Hanson and Olsson, 2020; Steiber *et al.*, 2020; Varajao, Trigo and Silva, 2021). Furthermore, Picoto, Crespo and Carvalho, (2021) note that the former theories are more suitable for explaining technology at the individual level. Meanwhile, Hanson and Olsson, (2020) and Steiber *et al.*, (2020) argue that DOI and TOE are the more robust theories for expounding technology adoption with regards to usage by firms/ entire organisations.

2.6.4. Rogers' (2003) Diffusion of Innovations Theory

First developed in 1962, the Diffusion of innovations theory theorise how new ideas, practices, or products are adopted across social systems (Rogers, 2003). The theory integrates previous sociological theories of behavioural change to explain the evolution of an innovation through the various phases of diffusion by different actors (Steiber *et al.*, 2020). The manner in which an innovation is communicated throughout a society and the subjective perceptions associated with the innovation are important factors in the rate of innovation diffusion (Perkins, 2011).

Furthermore, Rogers, (2003) categorises adopters of technology within a social system based on innovativeness. These adopters include (1) the innovator (active seeker of ideas); (2) early adopter; (3) early majority; (4) late majority; and (5) Laggards. Diffusion of innovations theory will enable presentation of a holistic view of innovation diffusion within a complex social system (the construction site). Furthermore, the diffusion of an innovation entails an innovation decision process as illustrated in figure 2.4 below. The decision process details prior conditions within a social environment, the introduction of the innovation, to the decision to implement the technology, as well as the evaluation of the attributes for continued or discontinued use (Iyamu, 2021). Therefore, using this theory, the researcher can "zoom" into a specific scenario where diffusion of a technology (drone technology) is being perceived through interaction – perceived attributes of the innovation(Varajao, Trigo and Silva, 2021).

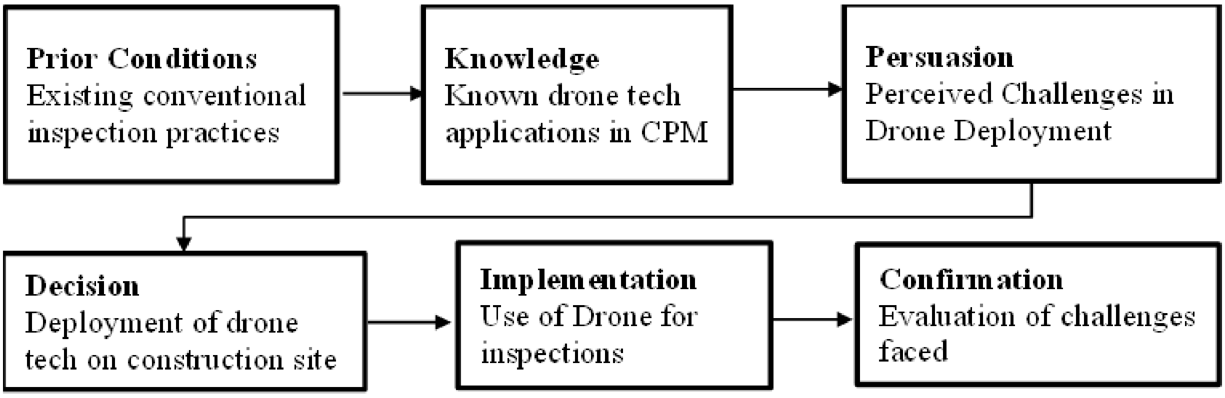

Figure 2.4: Illustration of Innovation decision process (adapted from Rogers, 2003)

2.6.5. Technology-Organisation-Environment Framework

TOE framework constitutes three contexts: technological, organisational, and environmental, that influence the adoption and implementation process by firms (Tornatzky and Fleischer, 1990). These contexts are used in predicting intention to adopt and implement a technology by firms (Jere and Ngidi, 2020). The technology context describes internal practices that firms embrace and technologies in current use, as well as those external technologies available in the market (Leunga *et al.*, 2015; Hanson and Olsson, 2020). This context draws on attributes of technology adoption underpinned by technological expertise of stakeholders, competency, and ICT infrastructure (Picoto, Crespo and Carvalho, 2021). Relative advantage, compatibility and complexity of a technological setting are influential factors in determining technological strength (Leunga *et al.*, 2015).

Furthermore, the organisational context denotes the firm's resources and characteristics that enable the successful adoption and operationalisation of an innovation. It focuses on organisational size, embeddedness, and complexity of the management structure, as well as communication channels as determinants of an organisation's ability to adopt a technology – organisational readiness (Ens, Stein and Blegind Jensen, 2018; Hanson and Olsson, 2020; Picoto, Crespo and Carvalho, 2021).

Martínez-Caro, Cegarra-Navarro and Alfonso-Ruiz, (2020) suggest that the support of top management is key in understanding perception towards technology adoption, available financial resources to effect adoption and operationalisation. Additionally, the environmental context addresses essential characteristics of an industry with regards to industry structure, regulations and service provision of technologies (Jere and Ngidi, 2020). This construct evaluates industry opportunities and constraints in terms government support, competitive pressure and external support. Figure 2.5 below illustrates the above-mentioned constructs of the framework.

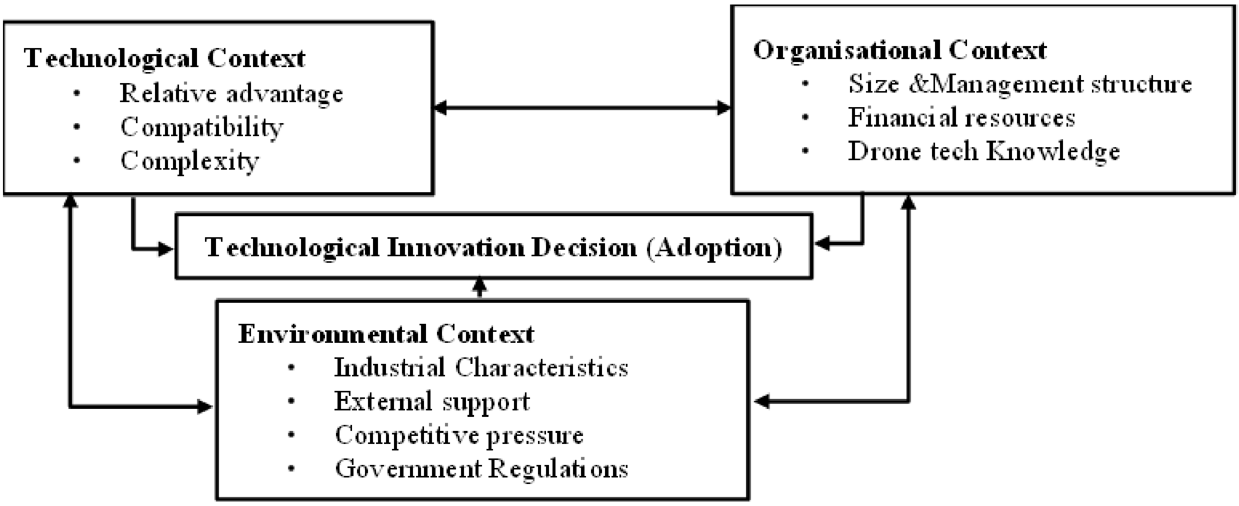

Figure 2.5: Application of TOE framework (Adapted from Jere and Ngidi, 2020)

2.7. Conceptual Framework

2.7.1. A Conceptual View of the Research Problem

In the previous section, a correlation between elements have been shown as to how they interact within their boundaries, in a harmonious manner. To this effect, drone technology is being introduced in an environment that would function without it. However, drone technology as a catalyst in construction project inspections presents possibilities where users, as part of the system can interact with the technology. Therefore, the amalgamation of Rogers' (2003) diffusion of innovations theory (focus on perceived attributes) and Tornatzky and Fleischer (1990) T-O-E framework to enable the development of a conceptual framework that illustrates relationships between research concepts (drone tech, inspections, construction). Investigating user (key role players) intentions in using drone technology and their subsequent usage behaviour (user perception) (Lee and Kim, 2018; Johnson, Adkins and Chauvin, 2020). Moreover, organisation, identification, and interpretation of the context in order to present and understand the construction site environment when drone technology is being leveraged for inspection procedure enhancing purposes.

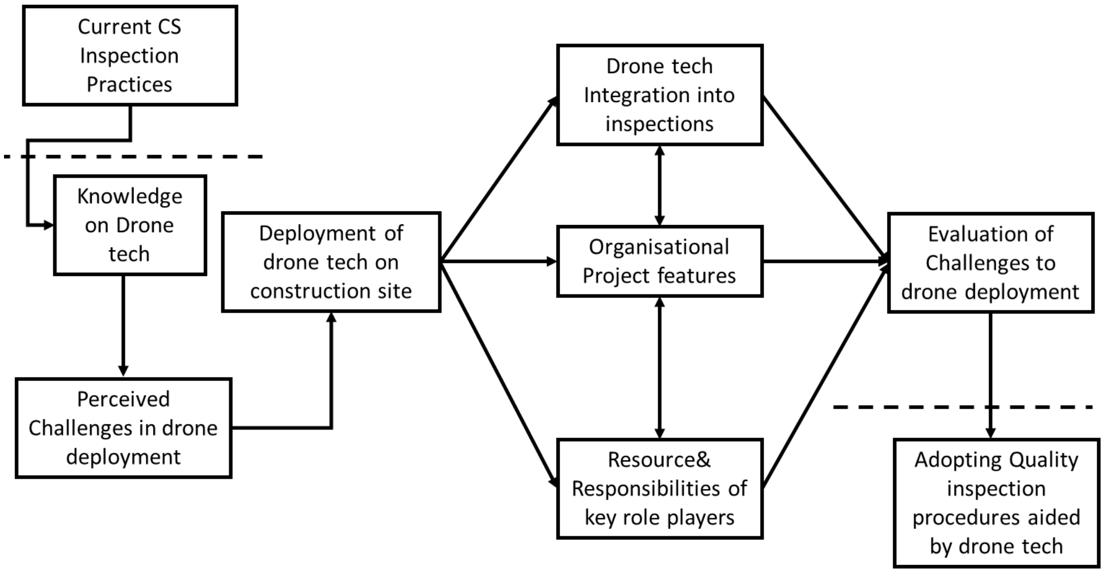

Figure 2.6: Conceptual Framework (from the study)

Figure 2.6 above illustrates the application of drone technology to a construction site organisational environment where challenges in the implementation of the technology and operationalisation to enhance inspection processes are explored. In the review of literature, it was discovered that SM limitations regarding CSM process enhancement are the case due to characteristics of SM, behaviour in site inspection expertise, as well as the current drone technology deployment capacity. These constructs fall within organisational and technological contexts of the construction site environment (Hanson and Olsson, 2020). Furthermore, the problem discovered which forms the main research question necessitates the need to observe inspections of construction works through utilisation of drone capabilities.

Real-time digitisation qualities of construction site inspection data capture is an overarching perception regarding complexity of incremental drone technology processes and compatibility of existing enterprise data management systems (Lee and

Kim, 2018). This fosters adoption of such incremental innovation which leads to drone-based real-time inspection process enhancement. Thus, mitigation of the challenges and improved operational adoption of the technology. More and more value would be derived from continued adoption of drone technology for real-time inspections.

2.8. Summary and key findings of the chapter

The industry's reliance on the manual management of processes and deliverables is an immediate influence of declining quality. Inspection procedures are still largely manual through physical access. There is still a lack of remote visualisation and control as well as real-time inspection data capture profusion in site management within African countries. The lack of digitised real-time inspection systems give rise to delays in conveying defects and inspection data for decision making.

Digital and automation technologies are currently the most significant trend in technological advancement within the global construction industry. Unprecedented technological platforms are being created through drone technology for automation of industrial assets, urban infrastructures as well as mega systems of consumer products. Furthermore, the increased use of information and communication technology has profoundly affected the planning, design, procurement, construction, and operation of the built environment in recent years.

The implementation of digital and automation technologies and processes is crucial in revolutionising the construction industry to facilitate new functionalities throughout the entire project value chain. However, there are certain challenges that are hindering the optimal implantation of drone technology in construction project management. Therefore, there is a need for comprehensive understanding on challenges in drone technology deployment and how such areas of weaknesses can be addressed in the drone-aided inspection implementation processes. Hence, empirical insights regarding the possibilities of CSM advancement through increased exploitation of digital technologies such as drone technology is required.

Findings from the literature review are that there are immense benefits from drone-aided inspections of construction works. Literature also revealed the need for construction site management to realise the need for drone technology application to enhance construction inspection process. Moreover, existing research has shown the significant impact of drone technology on the construction industry worldwide. Drones have proven to be valuable tools for improving inspection processes, monitoring progress, conducting surveys, and collecting real-time data from construction sites.

However, the adoption of drone technology for inspection process enhancement is suboptimal due to certain challenges that hinder its full deployment. As a result, there is a significant lack of focus on exploring the challenges that hinder the implementation of a technology aimed at addressing deficiencies in different aspects of CSM, despite the ineffective increase in human resources. Therefore, to explore these challenges, the researcher must systematically choose a research design that will provide certain techniques and tools to achieve the research aim. As such, the chapter that follows presents the research design of the study.

CHAPTER 3: RESEARCH DESIGN & METHODOLOGY

3.1. Introduction

This chapter discusses the appropriate methodological and methodical framework employed in order to coherently and logically integrate the overall aspects of the research. Thus, the chapter articulates a systematic approach for answering the research question, how the data collection and analysis procedures were approached in order to represent the findings more effectively. Basically, the research design focuses on the research philosophy and approach to theory development; research methods; data collection and analysis techniques and procedures; population and sampling; ethical considerations as well as the validity and reliability of the research. In summary, this chapter explains the philosophical perspective adopted for this study and offers a justification of the appropriateness of the use of the research methodologies as guided by the research aim.

3.2. Restating the research question to frame the research design

Before delving into the research design aspect of the study, it is critical for the researcher to identify the kind of information needed to achieve each objective and how the researcher will go about obtaining that information (Creswell and Creswell, 2018). The aim of this research is to assess the challenges hindering the deployment of drones on construction sites for drone-aided inspections by key role players during construction project execution. This aim having been derived from the research question in chapter 1, was segmented into three parts. These parts are the objectives (section 1.8) that will enable a design of a systematic approach to answering the research question as is the case in research.

The purpose of a research design is to outline a systematic and strategic plan that guides the researcher in conducting a study (Creswell and Creswell 2018; Azungah, 2018). It serves as a blueprint for obtaining answers to research questions and drawing meaningful conclusions. It plays a crucial role in defining the research's fundamental aspects, including the main question and theoretical underpinning, and aims to articulate what is to be achieved by the end of the study. Accordingly, research methodologies should align with the researcher's knowledge and insights to extract valuable results using various methods, whether used individually or in combination. This study involves the researcher closely engaging with the real-life experiences of participants and focuses on the emic perspective, capturing the insiders' viewpoints rather than an outsider's viewpoint.

3.3. Research Paradigm

A research paradigm refers to the philosophical framework or worldview that guides the researcher's approach to conducting research (Saunders *et al.*, 2016). It encompasses the set of beliefs, assumptions, and principles that shape the researcher's understanding of reality, knowledge, and the nature of inquiry. Furthermore, the choice of a research paradigm influences the researcher's perspective on how research should be conducted, the nature of truth, and the relationship between the researcher and the subject of study (Tombs and Pugsley, 2020). Intrinsically, there are three pillars of research paradigms which together provide a base on which the research can be developed. These are: epistemology, ontology, and axiology. Epistemology, which scholars define as the study of knowledge, encompasses the scope, methods, and means of acquiring knowledge as well as the means of validating the knowledge (Killam, 2013). On the other hand, ontology is a philosophical assumption regarding the nature of reality. The goal of ontology is to offer a comprehensive and final classification of all entities in all domains of existence (Saunders *et al.*, 2016). Thus, the existence of an influential relationship between ontological orientation and epistemological perspective. Lastly, axiology concerns the researchers’ beliefs and assumptions regarding value and ethics.

Hence, these three pillars are regarded as assumptions that guide research philosophies. Saunders *et al.,* (2016) define research philosophy as a set of beliefs and assumptions concerning the development of knowledge. These are certain mental frames, research paradigms, that guide researchers in designing and conducting research. The primary focus of research philosophy is the development of knowledge and its impact on the research methodology and methods (Bhattacharya, 2018). Creswell, (2014) identifies four main philosophies: constructivism, transformativism, post positivism and pragmatism. However, Saunders *et al.,* (2016) argue that there are five major philosophies through which knowledge can be developed: "*positivism, critical realism, interpretivism, postmodernism and pragmatism"* (Saunders *et al.*, 2016, p. 135).

Although a detailed explanation and discussion of each of these philosophies is beyond the scope of this research, it is important to highlight the distinctions between them in order to justify the most applicable paradigm to this research. Hence table 3.1 below presents a paradigmatic spectrum of the above-mentioned research philosophies, grounded on their epistemological, ontological and axiological assumptions. Positivism emphasizes the use of empirical and observable evidence, as well as the application of the scientific reasoning, to gain knowledge (Johannesson and Perjons, 2021). In the positivist paradigm, researchers aim to discover objective truths about the world through systematic observations and experiments. Therefore, this approach assumes that there is an objective reality that can be studied independently of the researcher and seeks to uncover general laws or regularities that govern phenomena (Saunders *et al.*, 2016; Creswell and Creswell, 2018; Nowell and Albrecht, 2019).

Table 3.1: Comparison of research philosophies (Adapted from Saunders et al., 2016)

Philosophical dimension	**Positivism**	**Critical realism**	**Pragmatism**	**Interpretivism**	**Postmodernism**
Epistemological assumptions	Natural laws are the basis for knowledge. Discovering and explaining occurrences allows for control and prediction.	Facts are social constructs	Flexible and problem-solving approach to knowledge. Practical consequences of beliefs and actions.	In-depth exploration and contextual interpretations to contribute new understanding	Dominant ideologies decide what counts as truth and knowledge.
Ontological assumption	One true reality ordered & governed by natural laws.	External reality independent of human beliefs & understanding.	Reality is complex and multifaceted, and different perspectives may be valid in different contexts.	Multiple, subjective realities influenced by human perspectives and experiences.	Multiple realities and parallel/divergent understandings constructed through power relations.
Axiological orientation	Objective, value-free research. Researcher is neutral and impassive	Value-laden research but the researcher tries to be as objective as possible	Value-driven research initiated and sustained by researcher's beliefs	Value-bound research where researcher interpretations are critical.	Value-constituted research where some narratives are repressed/silenced at the expense of others.
Typical methods	Quantitative	Multiple methods	Mixed or multiple	Qualitative	Qualitative
Objective					Subjective

Whilst closely related to positivism, critical realism seeks to bridge the gap between positivism and interpretivism by acknowledging the existence of an external reality that is not entirely dependent on human perceptions but recognizes the role of social constructions and interpretations in understanding that reality. Developed by philosopher Roy Bhaskar, critical realism is particularly applied in social sciences and aims to provide a nuanced understanding of the complex relationship between the observable world and the social, historical, and cultural contexts shaping our perceptions (Saunders *et al,* 2016). On the other hand, the pragmatic worldview posits that actions are linked to consequences in ways that are open to change. Moreover, pragmatism is concerned with methods that enable the discovery of credible, well-founded, reliable, and relevant data to advance research (Saunders *et al.*, 2016, p. 144). Consequently, pragmatism combines elements of both positivism and interpretivism and consider theories, concepts, and practicality of research findings in terms of roles they play as instruments of thought and action. Thus, enabling the pragmatist to reconcile different contextualised experiences, facts and values, accurate and rigorous knowledge, as well as objective and subjective stances (de Waal, 2021).

Conversely, interpretivism emphasizes the importance of understanding and interpreting the social world from the perspective of those involved. Unlike positivism, which seeks to discover objective truths through empirical observation and measurement, interpretivism focuses on subjective meanings and the context in which they are embedded (Husam and Pius, 2020). It is particularly suited to exploring complex social phenomena where quantitative measures may not fully capture the richness of human behaviour and interactions. In contrast, postmodernism is a philosophical and cultural paradigm that emerged in the mid-20th century as a reaction against the principles and assumptions of modernism. It is characterised by scepticism towards grand narratives, a rejection of absolute truths, and an emphasis on the relativity of knowledge and reality (Saunders *et al,* 2016).

3.3.1. View of the study

The focus of this study is to explore the challenges that are hindering optimal implementation of drone-aided inspections during the construction phase of a project. However, it is necessary to gain understanding of the level of diffusion of drones fit for construction inspection purposes to ascertain any factors that could be affecting deployment. Thus, it is important that prior to the empirical undertaking of the research, the researcher carries out a document analysis of current reports and documents relating to the nature of drone technology within the South African construction industry.

Fundamentally, from the research aim, it is evident that the researcher seeks to make sense of subjective and socially constructed meanings relating to the challenges impeding drone-aided inspections proliferation and to better understand their nature and occurrence. Ultimately, achieving this aim would require the researcher to interpret perspectives of the various key role players that would be involved in a drone-aided inspection process (Kitto, Chesters and Grbich, 2008; Malhotra, 2017). A review of extant literature in chapter 2 revealed that key role players in this context constitute the construction manager, construction site manager, drone operator, inspector, and the project manager as the client representative.

Therefore, the researcher will adopt the interpretive philosophy as a research paradigm to guide this research. Accordingly, the interpretivist world view emphasises that the ability of humans to create subjective and socially constructed meanings make them different from physical phenomena (Saunders *et al,* 2016, p140). Therefore, interpretivists contend that social sciences research should be differentiated from natural sciences research as human beings from different backgrounds, circumstances and times perceive and experience different realities. Moreover, interpretivism is concerned with methods that enable the creation of new, richer understandings and interpretations of social contexts (Junjie and Yingxin, 2022).

However, to achieve the goal of discovering the nature of reality from the view of participants, this paradigm accentuates qualitative analysis over quantitative analysis (Dudovskiy, 2018; Kassu, 2020). Consequently, interpretivism follows a naturalistic approach and employs data collection strategies such as interviews and observations (Husam and Pius, 2020; Elghaish *et al.*, 2021). Since interpretivism is underpinned by relativist ontology and subjective epistemology, its focus on complexity, richness and multiple interpretations creates an axiological implication of researcher subjectivity (Nha, 2021). However, the interpretivist should realise this implication and adopt an emphatic stance as noted in (Saunders *et al.,* 2016, p 141). From the extent of literature reviewed, studies that adopted this philosophy include (Golizadeh, Hosseini, Edwards, *et al.*, 2019b; Elghaish *et al.*, 2021; Falorca, Miraldes and Lanzinha, 2021b; London, Pablo and Gu, 2021).

3.3.2. Nature of study

The nature of a research study refers to its fundamental characteristics, objectives, and overall approach. Different types of research studies have distinct natures based on their purposes and methodologies. Based on the research aim: To assess the challenges hindering the deployment of drones on construction sites for drone-aided inspections by key role players during construction project execution, the study behoves an exploratory purpose. An exploratory study presents an effective way to ascertain the current state of a phenomenon to gain knowledge of and in-depth understanding about the topic of interest (Saunders *et al.,* 2016, p. 174).

Research driven by an exploratory purpose intends to discover new insights into a phenomenon and asses the phenomenon in new light through asking 'what'/'how' questions. This is an extremely useful means of clarifying the researcher's understanding of a topic of interest given the uncertainty of its nature (Lawrence, 2018). An advantage of exploratory research is its flexibility and adaptability to change. In most cases, exploratory research goals include: (1) scoping out the extent/magnitude of a certain phenomenon; (2) generating some initial ideas/hunches; (3) testing likelihood of understanding a more extensive study regarding the phenomenon (Bhattacherjee, 2012).

Considering the above-mentioned, exploring the challenges to drone technology application in construction would provide the researcher with in-depth understanding of the reality regarding drone use among construction professionals in South Africa. Therefore, painting a picture with regards to drone technology actualisation within the South African construction project management context.

3.4. Research Approach

Research approach implies the approach to theory development adopted in the study. There are various methods and strategies employed by researchers to formulate, refine, and articulate theoretical frameworks that explain or interpret a research phenomenon. According to Saunders, Lewis and Thornhill, (2019), there are three main approaches to theory development, each with its unique characteristics and methodologies: deduction, induction and abduction. Deduction is a reasoning approach that involves the development of a theory that is then systematically scrutinised through an array of propositions (Saunders *et al.,* 2016).

This process involves starting with a general theory, hypothesis, or premise and then examining specific observations or data to test the validity of that theory. Therefore, conclusions a logically formulated based on the consistency of several premises that are generally assumed to be true (Creswell, 2014). Facts, Laws, definitions, or properties are used to arrive at the conclusion. The deductive approach is commonly associated with positivist research paradigms, where researchers seek to uncover universal laws and causal relationships (Malhotra, 2017). However, a criticism of this approach in social sciences research is that the researcher is detached from the research subjects and formulated methodologies are rigid without permission of alternative explanations (Saunders, Lewis and Thornhill, 2019).

In contrast, inductive reasoning involves forming generalisations based on specific observations or evidence. It moves from specific instances to broader conclusions, and its logic is considered bottom-up (Malhotra, 2017). In this way, plausible premises are derived from specific and empirical observations to develop a theory. Inductive reasoning is commonly associated with interpretivist or constructivist research paradigms, where the goal is to understand and interpret the meaning of a phenomenon in its natural context (Junjie and Yingxin, 2022). In abductive reasoning, known premises are used to generate testable conclusions (Saunders *et al.,* 2016). Abductive reasoning is used when a person observes a set of evidence or phenomena and seeks the simplest and most likely explanation or hypothesis that can account for the observations. It is a valuable form of reasoning in various fields, including science and philosophy as it complements both deductive and inductive reasoning. While deduction involves deriving specific conclusions from general principles, and induction involves generalising from specific observations, abduction involves proposing plausible explanations for observed phenomena.

As noted above, Junjie and Yingxin (2022) states that the interpretivist world view primarily adopts an inductive approach to theory development. Furthermore, Saunders *et al.*, (2016) note that the adoption of induction as an approach to theory development becomes the case where the researcher is concerned with the context in which the phenomenon occurs (Saunders et al., 2016, p. 147). They state that a strength of inductive reasoning is establishing a cause-effect relationship between variables by developing an understanding of how individuals interpret their social environments. Likewise, inductive reasoning allows the researcher to construct a less structured methodology so as to reveal alternate explanations relating to challenges hindering optimal adoption of drone technology in construction project management (Creswell and Creswell, 2018; Dudovskiy, 2018; Kassu, 2020). Therefore, researchers who adopt this approach are primarily concerned with contextual inquiry, utilising qualitative data collection techniques to determine multiple views regarding the research problem. As such, an inductive approach will be employed in this study to develop theory. Hence, for this study, the researcher made broad generalisations using empirical evidence from specific observations.

3.5. Methodological choice for this study

Methodological choice describes the decision-making process involved in selecting the appropriate research methods and techniques to address specific research questions and objectives. The choice of methodology is a critical aspect of the research design driven by the nature of the research question, nature of the study, objectives, and the type of data needed to answer the research question (Mohajan, 2018). Furthermore, consideration should be given to how the collected data will be processed, analysed, and interpreted. Ultimately, the methodological choice is a strategic decision that shapes the entire research process. According to Saunders, Lewis and Thornhill, (2019) the researcher may use a single method (qualitative or quantitative) or a combination of the methods (mixed methods) to address the complexities of the research question.

Qualitative research enables the researcher to naturally comprehend subjective and socially constructed meanings conveyed regarding the phenomenon being studied (Saunders *et al.*, 2016). The constructs of qualitative research are associated with the interpretivist world view. Researchers work within a natural context and use various data collection techniques and analytical procedures to create a conceptual framework and contribute to theory. On the other hand, quantitative research focuses on the independent collection of numerical data and statistical analysis of research data. Relationships between variables are examined and numerically measured. Ultimately, they are analysed using a range of statistical and graphical techniques (Saunders, Lewis and Thornhill, 2019). The quantitative method is associated with the positivist paradigm as it originated from the philosophical belief that the world can only be understood through scientific observations governed by natural laws (Bless, Higson-Smith and Sithole, 2013, p. 15).

Conversely, the mixed method is a methodological choice that employs both qualitative and quantitative data collection techniques and analytical procedures as an approach of inquiry (Saunders, Lewis and Thornhill, 2019). This mixture of positions enables the researcher to obtain breadth and depth of understanding and corroboration concerning the research phenomenon. The mixed approach offsets intrinsic weaknesses in using either approach exclusively (Creswell, 2014). The manner in which both qualitative and quantitative approaches can be combined vary, they may be combined in a single form, concurrently, or in more complex and sequential forms (Saunders *et al.*, 2016, p, 170). This choice is often employed by pragmatists who view either the quantitative or qualitative research methodology as an end of a continuum contingent on the particular nature of the study (Tashakkori and Teddlie, 2010).

As discussed above, the interpretivist philosophy is often associated with the qualitative research methodology. Saunders *et al.*, (2016) state that this is because the meanings that the researcher must make sense of are subjective and socially constructed within a natural context (Saunders *et al.*, 2016, p. 168). Furthermore, it was noted that inductive reasoning is often used in qualitative research where a contextual research design is adopted in developing a richer theoretical perspective (Dudovskiy, 2018; Muthiah *et al.*, 2020; Maxwell, 2021). Therefore, this study will adopt the multi-method qualitative research methodology. Against this backdrop, qualitative research enables the researcher to naturally comprehend subjective and socially constructed meanings conveyed regarding the phenomenon being studied (Saunders *et al.*, 2016, p. 134). Thus, the researcher will operate within a natural context and employ an array of non-numerical data collection techniques and analytical procedures to develop a conceptual framework and contribute to theory. Thus, the ensuing sections details the research method, data collection techniques and analysis procedures used in this research as guided by the qualitative nature of the study.

3.6. Research Methods: Strategies, procedures and data collection techniques

Research methods are systematic procedures or techniques used by researchers to collect, analyse, and interpret data in a structured and rigorous manner. Remler and van Ryzin, (2021) define research methods as *"techniques and procedures that produce research evidence, such as sampling strategies, measurement instruments, planned comparisons, and statistical techniques".* The choice of research methods depends on the nature of the research questions, the type of data required, and the overall research design. Selected strategies, procedures and techniques for this study are guided by the research objectives, the coherence with which they link to the qualitative research design, the interpretivist philosophy, the inductive research approach, and the exploratory nature of the study. Moreover, as determined by Denzin and Lincoln, (2011) the extent of existing knowledge, research timeline and resources, as well as access to participants are factors.

3.6.1. Research strategies

A research strategy refers to how the researcher plans to answer the research question and how the methodology will be implemented. Fundamentally, this part outlines a methodological link between the research philosophy and the subsequent choice of methods for data collection and analysis. Different research philosophies have given rise to several potential research strategies, associating them with quantitative, qualitative, and mixed methods research methodologies. Nevertheless, Saunders *et al.*,

(2016) argues that the pivotal factor in choosing research strategies should be their capacity to allow the researcher to maintain sufficient coherence across the research and to achieve the research objectives by addressing the research question. As such, Saunders *et al.,* (2016) discuss these prominent strategies: Experiment; survey; archival and document research; case study; ethnography; action research; grounded theory; narrative inquiry. Upon the researcher's observation of these strategies, experiment and survey were deemed inappropriate; the research question does not lend itself to grounded theory, action research or narrative inquiry; and ethnography is not feasible. Hence, the most appropriate strategies to address the objectives are case study and documentary research (document analysis).

Case Study

A case study is a qualitative investigation into a phenomenon within a real-life setting. It permits an intensive and systematic inquiry about a person, a group of people or a unit with an aim to draw a general conclusion pertaining the unit (Bhattacherjee, 2012; Heale and Twycross, 2017). In exploring the phenomenon within a natural context, in-depth data relating to several research variables is obtained to increase understanding (Saunders *et al.,* 2016, p.184). Particularly, this exploration involves considering multiple perspectives and delving into the complexity and uniqueness of the subject matter (Johannesson and Perjons, 2021). A case study typically follows a structured format, including the problem, context, subjects to thoroughly analyse and describe various aspects such as individual activities, special needs, and real-life circumstances, providing comprehensive insights into individuals or collectives.

This type of method is among the earliest methods employed in qualitative research methodology (Malhotra, 2017). According to Mohajan, (2018), it has its origins in sociology and has proven to be particularly valuable in practical disciplines such as management, public administration, and education. The research is carried out using various sources such as interviews, observations, written accounts, and audio-visual materials to provide robust empirical evidence that enables contribution to a more compelling theory (Malhotra, 2017; Mohajan, 2018; Diop and Liu, 2020). Thus, facilitating a broader exploration of theoretical development and research inquiries. Essentially, case studies have the potential to achieve high conceptual validity, as well as providing rigorous procedures for developing new hypotheses (Mohajan, 2018). Moreover, case studies are useful for closely examining the hypothesised role of causal mechanisms within individual cases due to their capacity to address causal complexity (Diop and Liu, 2020; Johannesson and Perjons, 2021). Álvares, Costa and Melo, (2018) explored the potential application of drones for 3D mapping of construction sites through two case studies developed in residential projects; Chen *et al.*, (2021) utilised a case study approach to validate geo-registration methods proposed for building façade inspections using a GIS-based spatial model; Devers, (2019) used a single case to explore the use of drones in heavy civil construction projects; Falorca and Lanzinha, (2020) purposefully tested three cases to consider the effectiveness of using drones for visual inspections; Munawar *et al.*, (2022) tested a drone-based CNN architecture for crack detection on mid to high rise buildings, using Sydney, Australia as a case.

Document analysis

Document analysis is a systematic process for assessing written or digital documents that were created independently of the researcher (Bowen, 2009). According to Nowell and Albrecht, (2019) document analysis requires data to be studied and interpreted in order to extract meaning, obtain understanding, and build empirical knowledge as is the case with other approaches used in qualitative research. Hence, excerpts, quotations, or complete sections are obtained by document analysis and are then organised precisely through content analysis into primary themes, categories, and case examples (Nowell and Albrecht, 2019; Muthiah *et al.*, 2020; Morgan, 2022). Essentially, this procedure involves searching, choosing, evaluating, and synthesising data from documents. Documents that analysed in this study include manuals; background papers; books and journals; organisational or institutional reports; and public records. These types of documents are found in libraries, organisational or institutional archives, and public domains. According to Morgan, (2022), the researcher must go through a thorough procedure in order to obtain accurate results. As such, this study adopts O'Leary's (2014) proposed eight-step procedure for archival research (O'Leary, 2014). These steps are described below.

1. Gathering relevant texts: the researcher decides on the types of documents that will be used and list the resources. For this study, documents published the last ten years were gathered.
2. Developing an organisation and management scheme: having listed the resources, units of meaning and set of categories were defined. These are elements and characteristics of the content.
3. Making copies of original documents for annotation: Annotations were done digitally using adobe acrobat.
4. Ensuring authenticity of documents: Only authoritative sources with credible authors were be selected. Therefore, credibility and legitimacy of documents was be evaluated.
5. Explore document's agenda, checking for biases: in this step, the researcher inspected the level of bias in the selected documents. Types of bias evaluated are confirmation bias, culture bias and wording bias.
6. Exploring background information: In this step, the tone, style, purpose of the document were elements explored.
7. Asking questions about document: The Who, what, when, where and why types of questions were asked when assessing information so as to gather important details.
8. Exploring content/ evaluating the document: in this last step, the researcher extracts useful information which is then interpreted and used to develop the study. In essence, after deciding what is being searched for, the researcher records and arranges the frequency and occurrences within the content. The data is then arranged according to what is relevant to the research's main questions (Morgan, 2022).

Essentially, documents were evaluated by categorising their content into separate themes, much like transcripts from interviews and focus groups. Thus, generating a confluence of evidence that is credible. Conspicuously, document analysis is an extremely valuable social research approach that plays an important role in inductive research to explore a specific topic.

3.6.2. Data collection techniques

Qualitative data can be collected from primary or secondary data sources. Primary data is typically collected through interviews with experts in the relevant topic. According to Muthiah *et al.*, (2020), it is important for qualitative researchers to engage in communication with practitioners in the organisational context. This allows for a deeper understanding of the current state of real-world practices. The secondary data includes publications provided by participants to the researchers, as well as publicly available data that is relevant to the observed topic (Hennink, Hutter and Bailey, 2020).

Contextual inquiry

Contextual inquiry is a technique where interviews are conducted before observing a phenomenon in the context of use and after (Duda, Warburton and Black, 2020). Contextual inquiry stems from the contextual research design by Holtzblatt and Beyer, (1997). This strategy is so much more than just a technique as it represents a particular worldview of how people interact in a shared inquiry and discovery of empirical knowledge (DeJonckheere and Vaughn, 2019; Duda, Warburton and Black, 2020). The guiding principles in contextual research entails (DeJonckheere and Vaughn, 2019):

1. Determining important activities for the successful inquiry.
2. Partnership: the interviewer observes as the participant behave within the contextual setting.
3. Interpretation: creating a shared understanding of the user experience.

From the review of extent literature, studies where this data collection procedure was employed include (Melo *et al.*, 2017; Asadi *et al.*, 2020; Kim and Irizarry, 2020; Suleiman, 2022). Through observation, the researcher observes a process that is being explored (Muthiah *et al.*, 2020). By observing events as they occur in the natural setting, the researcher gains deep contextual interpretations of these events.

Interviews

Qualitative research interviews are techniques used to understand the world from the point of view of the subjects to interpret the meaning of their experiences (Muthiah *et al.*, 2020). They involve engaging participants in structured, semi-structured or unstructured conversations to gather in-depth information, insights, and perspectives on a particular topic of interest (Johnson, Adkins and Chauvin, 2020). According to Saunders *et al.*, (2016), research interviews are conducted to explore, understand, and interpret participants' experiences, beliefs, attitudes, behaviours, and opinions related to the research topic. Therefore, interviews offer a valuable method for gaining a deep understanding of complex phenomena, capturing diverse perspectives, and generating rich qualitative data that can inform theory, practice, and policy in various fields (Johnson, Adkins and Chauvin, 2020; Johannesson and Perjons, 2021). Hence, the reason for using interviews as a strategy is to gather rich, detailed data that cannot be easily captured through other methods such as surveys or experiments. Interviews can be conducted in-person, over the phone, or through video conferencing, depending on the preferences and logistical constraints of the participants and researcher (Saunders *et al.*, 2016).

3.6.3. Justification of strategies, procedures and data collection techniques

To ascertain the diffusion of commercial drones for construction related applications within the South African construction industry, data was gathered using documents obtained from drone market reports, policy documents and service providers/operators reports. These types of documents were found in organisational websites/institutional archives, and public domains. Drone market documents were used to ascertain the nature of the South African drone industry. Policy documents were used to understand the impact of the regulatory environment on the accessibility of commercial drone market for the construction industry and the involvement of the piloting community in influencing the growth of the market. Service providers reports supplemented the evaluation of the extent of availability of commercial drones for construction-specific applications.

The second objective was to determine the nature and occurrence of challenges to drone technology deployment for drone-aided inspections during construction. This objective was achieved by gathering data through a case study strategy that followed a contextual inquiry procedure and interviews as a technique to solicit information from the participants. Collectively, these enabled the researcher to determine the perceived challenges and experienced challenges. Furthermore, the researcher was able to observe the nature and occurrence of these challenges. Interviews were also used to collect data on suggestions on how to address the identified challenges impeding optimal utilisation of drone technology.

3.7. Research population and sampling

Sampling is a technique that enables the researcher to reduce the amount of data that the researcher collects by considering a sample within a population (Saunders *et al.*, 2016). A sample is a subgroup within a population (target population) from which data pertaining to the characteristics of the population can be obtained to generalise inferences about the unknown population parameters (Bless, Higson-Smith and Sithole, 2013; Dudovskiy, 2018; Saunders, Lewis and Thornhill, 2019). Bless, Higson-Smith and Sithole, (2013) argue that the sample should accurately represent the entire population in a meaningful way that is also justifiable (Bless, Higson-Smith and Sithole, 2013, p. 163).

The target population for this study mainly comprised of project managers, construction managers, construction site managers working for clients and contractors; government representatives on public construction projects; drone pilots, operators and service providers who provide construction related drone technology services. Professionals from government were those involved in the implementation of drone technology on government contracts. For the contextual inquiry, the cases were chosen from residential, commercial and infrastructure construction projects.

The main method of sampling used in this study was purposive sampling. However, due to the lack of an exhaustive database and limited practice of drone technology, snowballing was also applied. Purposive sampling is a non-probabilistic sampling technique where the researcher deliberately selects participants who possess specific characteristics or knowledge relevant to the research objectives (Kassu, 2020). The participants identified through purposive sampling were asked to identify and refer other potential participants who meet the criteria, thus creating a snowball effect (Busetto, Wick and Gumbinger, 2020).

Purposive sampling was applied by identifying potential participants from the literature review process such as the Gauteng Department of Infrastructure

Development. Moreover, internet searches provided information on drone service providers who provide their services to construction projects. These individuals were contacted via LinkedIn and through the company email found on the website. The snowballing technique was applied by identifying participants through these individuals after having agreed to participate in the study.

The target population for the document analysis was drone market reports, policy documents and service providers' documents published after the issuing of drone regulations and commercial drone licence by the SACAA in 2015. Purposive sampling was also used to select these documents for analysis. The aim was to gather 25 of these documents. However, only 15 were retrieved: 6 market reports, 5 policy documents and 4 from service providers.

3.8. Research instruments

The research instruments are measurement tools which the researcher designs to obtain data from the research subjects (Kassu, 2020). The nature of the study necessitated the use of secondary data through document analysis, interview questions and direct observation to obtain the required data to answer the research question (Saunders *et al.*, 2016, p. 437). Drawing from Falorca *et al.*, (2021), a list of semi-structured interview questions was designed and developed prior to the data collection.

3.8.1. Semi-structured interviews

Semi-structured interviews are used to collect data with key participants who have personal experiences, attitudes, perceptions, and beliefs relevant to the research issue. Thus, the researcher can gather fresh, exploratory data to answer the research question using semi-structured interviews (McGrath, Palmgren and Liljedahl, 2019; Nowell and Albrecht, 2019; Maxwell, 2021). Accordingly, DeJonckheere and Vaughn, (2019) argue that when a researcher wishes to gather qualitative, open-ended data, delve deeply into a phenomenon, and investigate participant perceptions and lived experiences about a certain topic, semi-structured interviews are an efficient way for doing so. Evidently, this data collection technique was used by researchers such as (Nielsen, 2017; Devers, 2019; Asadi *et al.*, 2020; Kim and Irizarry, 2020; Suleiman, 2022). Therefore, semi-structured interviews were conducted in addressing objectives 2 and 3.

3.8.2. Non-Participant Observation

Through observation, the researcher observes a process that is being explored (Muthiah *et al.*, 2020). By observing events as they occur in the natural setting, observers can gain deep contextual interpretations of these events. Therefore, non-participant observation is a qualitative data collection technique for acquiring first-hand information about a particular area of the social world without actively engaging with its participants (Hennink, Hutter and Bailey, 2020). Essentially, it is, a more structured observation techniques where the researcher observes participants while they are aware of it and without actively participating (Saunders *et al.*, 2016, p. 366). This technique was employed by researchers such as (Albeaino and Gheisari, 2021; Falorca and Lanzinha, 2020; Nielsen, 2017; Rey *et al.*, 2021; Suleiman, 2022).

3.8.3. Focus group

A focus group is a qualitative research method that involves gathering a small, diverse group of individuals to participate in a structured discussion led by a moderator (Saunders *et al.,* 2016). This method aims to explore participants' perceptions, attitudes, opinions, and experiences regarding a specific topic of interest in a collaborative and interactive setting. Johannesson and Perjons, (2021) states that focus groups are often used in market research, social sciences, psychology, product development, and program evaluation.

Although it was not the researcher's primary intention to use focus group as a data collection technique, it was incorporated into the study after having conducted the first case study. At this point, difficulty was experienced when attempting to conduct follow up interviews with participants who were interviewed then observed during drone deployment. This prompted the adoption of a focus group technique for the remaining two cases. In turn, this technique worked better as supposed to individual follow up interviews. Participants were asked to be part of the focus group session straight after the observation while still on site.

3.9. Data collection protocol

Data collection protocol is the procedure the researcher follows in applying the research instruments to collect data (McGrath, Palmgren and Liljedahl, 2019). This involves inquiring and eliciting responses as well as recording the responses to ensure admissibility of data (Remler and van Ryzin, 2021). According to Muthiah *et al.*, (2020), accurate data collection is important in maintaining the structure and integrity of the research. Thus, appropriate data collection instruments and delineated instructions ensure a reduction in the likelihood of errors. Research instruments were developed to achieve objectives 2 and 3. Thereafter a protocol which is provided below in table 3.2 was followed during the data collection process.

Table 3.2: Protocol for data collection

Contextual inquiry & interviews	**Protocol**
Ethical Clearance:	Gained ethical clearance from Wits University.
Participant Recruitment:	Contacted possible participants matching population criteria via phone or email. Elaborated on the study and provided participant information sheet and consent form. Obtained consent for participation.
Follow-Up Communication:	Sent follow-up emails if no response after initial contact. Considered unwilling to participate if no response after follow-ups.
Further Communication:	Initiated further communication via email upon participant's willingness to participate.
Scheduling Interviews, site visit.	Asked participants for convenient day, time, and online platform for interview. Scheduled meeting based on participants' preferences.
Reminder and Consent Form:	Sent reminder email regarding consent form if not yet received. Obtained signed consent form prior to interview, observation.
Consent Details:	Participants consented to various aspects including anonymity, quoting anonymously, and audio recording.
Permission for Recording:	Requested permission for recording before interview commencement. Started recording with participant's permission.
Data Handling:	Stored audio recordings on password-protected computer. Transcribed recordings excluding personal details, ensuring accuracy

3.10. Time horizon of the study

The research time horizon refers to the duration or time period over which a research study is conducted or observed. Cross-sectional studies pertains to research where data is collected from subjects at a single point in time by the researcher (Heale and Twycross, 2017). On the other hand, longitudinal studies involve data collection from the same subjects over an extended period (Saunders, Lewis and Thornhill, 2019). This allows researchers to track changes or developments over time and investigate cause-and-effect relationships.

This research, being undertaken for an academic course, is time constrained. Moreover, it is a study of a particular phenomenon – exploration of challenges to drone technology proliferation for enhance site inspections – at a particular time. Hence, it is a cross-sectional study (a 'snapshot' of a phenomenon at a particular time) that will employ qualitative research strategies encompassing case study strategy and interviews conducted over a short period of time (Saunders *et al.*, 2016, p. 200.).

3.11. Validity, reliability and generalizability

Validity and reliability in qualitative studies are crucial components of research quality which help distinguish between high-quality and low-quality research when used carefully (Thakur and Chetty, 2020). Additionally, they reassure readers that the results of the study are reliable and trustworthy (Luhanga and Harbaugh, 2021). This factor becomes especially important in case studies that analyse primary data because researcher's subjectivity can have a significant impact on how the findings are interpreted. For instance, Johnson, Adkins and Chauvin, (2020) adopts the perspective of Meyrick, (2006) stating that for high quality qualitative research, the basic dichotomous criteria of systematicity and transparency be satisfied. Accordingly, if the research process is transparent or methodical enough, each step including theory development, research design, sampling, data collection and analysis, outcomes, and conclusions—must be validated (Leunga *et al.*, 2015; Hayashi, Abib and Hoppen, 2019; Maxwell, 2021). In this way, the rigor and robustness of the study process and results may be guaranteed (Hayashi et al., 2019). Furthermore, Leung, (2015) emphasises (1) clarification and justification; (2) procedural rigor; (3) sample representativeness; and (4) generalisability as criteria for evaluating the general validity and reliability of qualitative research.

3.11.1. Validity

In qualitative research, validity is referred to as the participants' accounts of the social phenomenon being true to their experiences (Thakur and Chetty, 2020). Similarly, Nha, (2021) refers to validity as the appropriateness of the research methods and tools as tenants of the underlying philosophical framework. Therefore, to develop a valid qualitative study, the methodology must be appropriate, the design must be valid for the methodology, the sampling and data analysis must be valid for the methodology, and the results and conclusions must be valid for the sample and context (Leung, 2015; Thakur and Chetty, 2020; Nha, 2021).

Furthermore, it can be argued that qualitative studies are validated by "trustworthiness" and "rigor," as opposed to quantitative research, which uses statistical or experimental procedures to ensure validity (Leunga *et al.*, 2015; Maxwell, 2021). However, the value of truth, neutrality, and applicability all play a role in this (Nasseri and Aulin, 2016; Hammad *et al.*, 2021). According to Leung (2015)), Hayashi, Abib and Hoppen (2019), Thakur and Chetty (2020), and Nha (2021, the following measures are used to maintain trustworthiness and rigor, hence, assuring internal and external validity in qualitative research:

- Considering individual biases to ensure results are unaffected.
- Ensure data collection process and analysis are thorough and relevant.
- Establishing a comparison of viewpoints to examine similarities and differences
- Keeping meticulous records to ensure a transparent data interpretation process.
- Including detailed verbatim accounts from participants to substantiate findings.

Furthermore, the most common strategy to uphold validity in qualitative research is validation through respondents. Here, the researcher asks research subjects to double-check how the transcripts are presented, along with the themes and concepts, and how well they match the problem being studied (Maxwell, 2021). Therefore, this is the strategy that was used in this study to achieve validity.

3.11.2. Reliability

Reliability is defined as the consistency with which instances are classified into the same category by multiple observers or by the same observer at different times (Nha, 2021). Instead of focusing on providing reliability estimates for data, qualitative researchers often concentrate on describing methods that increase the accuracy of their approach (Johnson, Adkins and Chauvin, 2020). For instance, Silverman, (2015) applies "low inference description" techniques to texts, interviews, and observations. Basically, a low-inference description aims to give as much concrete information as possible without alteration of meanings. To enable readers to critically evaluate the findings, low-interference description demands researchers to present specific and tangible data without researcher re-construction (Hayashi, Abib and Hoppen, 2019; Silverman, 2019; Thakur and Chetty, 2020).

Since qualitative research focuses more on understanding people's experiences, its reliability is not heavily dependent on the quantity of people who have encountered the same phenomenon (Guest, Namey and Chen, 2020). Rather, reliability measurements are a component of quantitative research where the researcher is required to demonstrate that the procedure and the findings are repeatable. However, reliability in qualitative research encompasses a wide range of paradigms and is epistemologically counter-intuitive (Thakur and Chetty, 2020). Therefore, consistency is key in upholding reliability in qualitative research.

According to Johnson, Adkins and Chauvin, (2020), as long as the adopted methodology and epistemological paradigm consistently provide data that are ontologically comparable but may differ in richness, a margin of variability for outcomes is acceptable in qualitative research. Consequently, these techniques substantiate reliability claims in terms of form and context. As such, reliability was maintained through the use of concrete data, ongoing testing and comparison of data, and the use of tables to store data. NVivo software was used to formally organise the data and verify its validity.

3.11.3. Generalisability

The term "generalisability" refers to the extent to which results from the study sample can be applied to the entire population (Azungah, 2018). Although qualitative studies do not claim to be generalisable in the conventional sense, they do have other redeeming qualities that make them extremely valuable academia (Maxwell, 2021). However, making partial generalisations to comparable populations is not a primary concern in qualitative research. According to researchers, generalisations made about a single result are just as valid as those made about several discoveries, even though the combination of individual investigations enables theory development using tentative hypotheses (Silverman, 2019; Johnson, Adkins and Chauvin, 2020; Muthiah *et al.*, 2020).

On the other hand, Leung (2015) opines that the aim of qualitative studies should be considered when evaluating the generalisability of such research study. However, issues relating to sampling may have insignificant influence on the generalisability of the study (Leung, 2015; Thakur and Chetty, 2020). As such, a small sample size is frequently preferable to a big sample size when thoroughly studying a phenomenon through a qualitative approach.

3.12. Data analysis Procedures

The aim of data analysis is to differentiate weather the occurrence of events is reflecting a true or false effect by analysing collected data to clarify the nature of the element in parts and the relationships between them (Saunders *et al.*, 2016, p. 247). Therefore, data analysis techniques adopted in this study include content analysis (Mohajan, 2018) and thematic analysis (Bowen, 2009). Data analysis occurred simultaneously with data collection, which is typical in qualitative research.

3.12.1. Content analysis

Thakur and Chetty, (2020) defines content analysis as an analysis technique that uses systematic coding to classify text data, discover themes, and then interprets those themes or patterns. However, Mohajan, (2019) refers to content analysis as a thorough systematic analysis of the information in a certain body of work with the goal of finding trends, themes, or biases. Contrary to statistical analysis, content analysis does not quantify or measure trends, instead, it is based on analysing viewpoints and experiences on contextual phenomena (Thakur and Chetty, 2020). A strength of content analysis is the step-by-step analysis of every element of the data collected into themes (Maxwell, 2021). Listed below are the 8 steps in content analysis (Silverman, 2019; Kyngäs, 2020) which the researcher adopted for the content analysis of data gathered under objective 1 of the study.

1. Preparation of data: The researcher must define and justify choice of content based on the data sets obtained. The following questions must be addressed by the researcher before beginning data analysis: Whether to transcribe all the data gathered; should accounts be recorded verbatim; should transcriptions of observations be included?
2. Defining the unit or theme of analysis: Organising the content into units or themes, which can be a word, phrase, or sentence and including information pertinent to the theme to that unit.
3. Developing defined categories and coding scheme: construct sub-categories and coding strategy derived from primary data, relevant theories, and empirical cases.
4. Pre-testing the coding scheme on sample: It is also crucial in qualitative research to pre-test and code the sample of existing data to maintain consistency.
5. Coding all the text: It is critical to use the coding process on the data after the coding consistency in stage 4.
6. Assessing the consistency of coding: Validity and reliability of the entire data collection should be evaluated after coding.
7. Drawing inferences based on coding or themes: Draw inferences based on the generated codes and categories and explore the characteristics, patterns, and relationships to present analysis.
8. Presentation of results: present results backed by secondary data and quotes from the created code to display them under each theme with conclusions. The researcher displayed the findings in the form of graphs and tables.

Furthermore, as was suggested by Thakur and Chetty, (2020) NVivo software package was used as a data analysis tool. NVivo software is a qualitative data analysis software which provides accurate and transparent results from processed data (Dudovkiy, 2018; Maxwell, 2021). Data from the integrative literature review and case study interviews was analysed using this software as they are qualitative in nature.

3.12.2. Thematic analysis

Thematic analysis entails the identification of patterns within the data and the utilisation of emerging themes as the foundation for analysis (Creswell and Creswell, 2018). The process involves a thorough and focused reassessment and evaluation of the data. The researcher thoroughly analyses the collected data and performs coding and category construction to identify pertinent themes related to the specific phenomenon. According to Guest, Namey and Chen, (2020), the use of codes and the resulting themes they create are essential in incorporating data gathered from the selected research methods. However, the researcher should strive to maintain objectivity and present a balanced representation of the research material. Furthermore, it is important to be attentive to subtle cues when selecting and analysing the collected data (Creswell and Creswell, 2018; Guest, Namey and Chen, 2020).

Figure 3.1 below provides the process for coding and developing themes used for this study. The data collected from interviews, observations and the two focus group sessions were transcribed and coded to enable thematic analysis. Having understood the transcribed data, it was then uploaded into NVivo14 for processing. The analysis was then performed, and an iterative process was used to develop and refine the codes. Thereafter, these themes were interpreted to derive meaning.

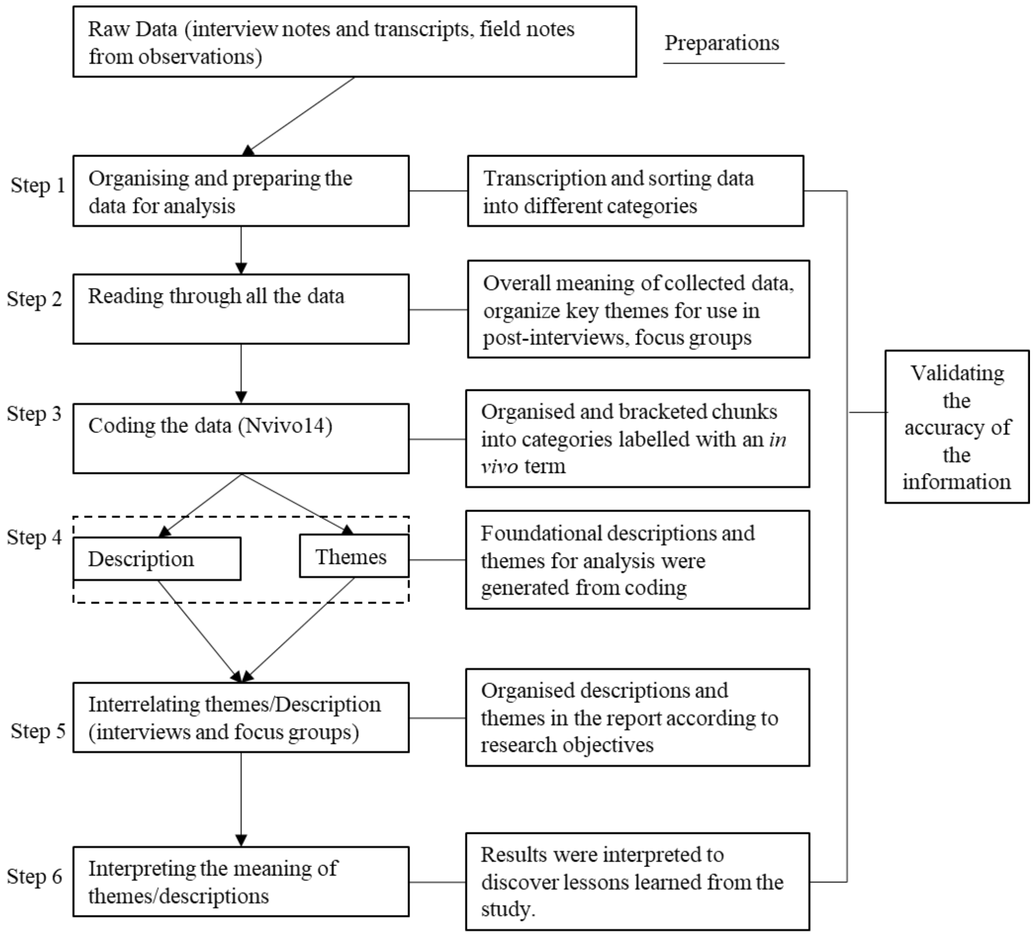

Figure 3.1: Data analysis for qualitative research (adapted from Creswell and Creswell, 2018)

3.13. Ethical risks and mitigation

Ethical considerations are one of the fundamental components of a research study which demonstrate that the researcher has considered all requirements for developing an ethically valid study (Bhattacharya, 2018; Hennink, Hutter and Bailey, 2020). The researcher kept all ethical standards of behaviour that are set out by the University throughout the research. These standards are set out so as to foster academic research that promotes the pursuit of knowledge and truth without fabrication and/or falsification of data (McGrath, Palmgren and Liljedahl, 2019; HREC Wits University, 2021; Knight, 2021). To adhere to the ethical standards for the entire duration of the research, ethical issues that were considered are stipulated in table 3.3. The table describes how ethical risks were addressed throughout the study (Thakur and Chetty, 2020; Knight, 2021).

Table 3.3: Ethical risks and mitigation strategies

Phase of Research	Ethical Risks	Ethical Risks Mitigation
Formulation and Clarification of the Research Topic	Integrity and Objectivity. Cognition of Conflicting interest.	The researcher took cognisance of the responsibilities to ensure all sources used were properly acknowledged
Research Design and Gaining Access	Informed Consent. Privacy. Voluntary Participation.	Ensured no coercion and fully informed participants on the research. Participants were allowed to ask questions and their informed consent was required prior to solicitation.
Data Collection	Coercion by researcher. Avoiding of deception. Informed consent and voluntary participation. Discontinuance. Confidentiality and Anonymity.	Ethical clearance was obtained from Wits HREC before data collection took place. Objectivity was maintained; consent was informed, and participants were told of their right towithdraw during interviews. Privacy, confidentiality, and anonymity rights were respected. Participant right to privacy was maintained throughout.
Data Processing and Storage	Ethical analysis and reportingIntegrity and Objectivity. Confidentiality and Anonymity	Agreement of consent was observed, maintained confidentiality and anonymity.
Data Analysis and Reporting of Findings	Data management compliance. Confidentiality and Anonymity.	Objectivity in analysis and reporting of findings was maintained. The right to quality research and publicationof results was observed.

As outlined in Table 3.3 above, general ethical issues include integrity and objectivity; voluntary participation; respect; confidentiality and anonymity; privacy; safety; avoidance of harm; data management compliance; and responsibility in analysing and reporting (Saunders et al, 2019). Risks such as privacy breaches and coercion were mitigated by obtaining informed consent from participants, ensuring voluntary participation, and explaining the research process to them. Participant information sheets and consent forms were designed following the Wits ethics committee guidelines. These documents were submitted to the Wits ethics committee and approval was given to the researcher to begin data collection.

The data collection process presented ethical challenges such as potential coercion and ensuring confidentiality. To address these issues, participants were informed that their participation is voluntary and that they had the right to withdraw at any point during the data collection process. By addressing these ethical risks comprehensively, the researcher was able to conduct a contextual inquiry that respects participants' rights and upholds ethical standards, ensuring both the quality of the research and the well-being of those involved.

In interviews and focus groups, each participant received detailed information about the research objectives and how their data would be used. Signed consent forms were obtained from those individuals who actively participated. Furthermore, informing the site personnel about the study's goals, even when they were not actively participating, was important to ensure that no one was unknowingly observed. Any personal information or behaviour observed was kept confidential and not linked back to the personnel around the site.

However, anonymity was especially challenging in focus groups because participants were aware of each other's identities. To mitigate this risk the researcher had to remind participants of the importance of maintaining confidentiality regarding what is shared within the groups ensuring everyone is aware that comments should not be discussed outside the session.

On the other hand, Saunders et al. (2016) highlight the importance of data protection measures in compliance with laws such s the Protection of Personal Information Act, ensuring sensitive information remains secure and only accessible to the researcher. The researcher ensured data was stored securely in a password protected device, and participants' anonymity was preserved. Protecting confidentiality in interviews and focus groups involved securely storing participant data (i.e., anonymised transcripts) using pseudonyms or coding systems such as C1P1, C2P2, and C3P1 to ensure data cannot be traced back to the research participants. Finally, in data analysis and reporting, objectivity was maintained by adhering to ethical guidelines, avoiding bias in interpretation, and ensuring that findings were reported accurately.

Throughout the research, maintaining transparency, upholding participants' rights, and adhering to ethical standards were critical in mitigating the ethical risks. The mitigation of these risks highlights the efforts by the researcher to maintain integrity throughout the research process. Thus, the explanation of how each risk was addressed reflects an understanding of the principles and responsibilities that are foundational to good research practice (Lingard and Watling, 2021).

3.14. Summarising the research design

The design encompasses the systematic arrangement of methods and procedures employed, the manner in which it is carried out in relation to the target populations, the process of selecting samples, the instruments utilised, and the duration of the study. With the identification of all components of the research method, it is now necessary to ensure that each piece is properly placed. As noted in Mohajan, (2018), a researcher conducting a qualitative study must adhere to fundamental principles of research design. This includes establishing a strong connection between the research questions and the chosen methodological approaches, recognising the interdependence of analysis and data collection, and maintaining clarity regarding the research objectives as presented in table 3.4 below.

Table 3.4: Research Methods – Strategies, Data Collection & Analysis Procedures

Objective	Research Method	Data Collection Strategy	Data Collection Procedures	Data Analysis & Presentation	Data Analysis Software
To ascertain the diffusion of commercial drones for construction related applications within the South African construction industry.	Documentary research	Document analysis	Secondary Data Collection	Content Analysis	NVivo Software
To determine the nature and occurrence of challenges to drone-aided inspections.	Case Study	Contextual inquiry	Semi-structured interview Non-participant Observation	Thematic Analysis	NVivo Software
To suggest ways of addressing identified challenges impeding optimal utilisation of drones during construction execution.	Case Study	Interview	Semi-structured Interviews	Thematic Analysis	NVivo Software

3.15. Chapter Summary

This chapter outlined the methodological approach that the researcher adopted to answer the research question. Research methods, techniques and strategies chosen were informed by the exploratory nature of the study, inductive reasoning and the interpretive paradigm through which the researcher explored the phenomenon in question. As such, the qualitative method was selected with case study observations and semi-structured interviews chosen as data collection techniques. The participation of human beings necessitated the discussion of the relevant ethical issues. To present findings that are valid, reliable and generalisable, NVivo software was used as a data analysis tool where content analysis and thematic analysis were employed as data analysis strategies. The selected research methods in this study are sensitive to the research needs and deemed appropriate for the type of study conducted. The utilisation of qualitative, inductive case studies within an interpretivist paradigm was considered necessary to deepen the understanding of the nature and occurrence of the challenges impeding key role players from full adoption of drone technology for construction site inspection processes.

CHAPTER 4: PRESENTATION OF DATA FINDINGS AND ANALYSIS

4.1. Introduction

Chapter 3 discussed the research design employed in this study. This chapter presents the findings from the document analysis, the case studies, and the interviews relating to objectives 1,2 and 3 respectively. These findings address the three research questions with reference to the research objectives and the literature review. Data from the document analysis was analysed based on content analysis and the data from the case studies and interviews was analysed based on thematic analysis. NVivo 14 was used for both these analyses. However, descriptive and pattern coding was used.

For the document analysis, 15 documents were used. On the other hand, three cases were selected for the case study with 15 participants involved across the three cases. Lastly, the interview process to achieve objective 3 involved 11 participants. The data collected from interviews were transcribed using Microsoft Word. The transcripts then underwent a thorough cleaning process to rectify any transcribing errors as well as organising the data according to the proposed methodology in chapter 3 under section 3.12 (figure 3.1). This assisted in rectifying grammatical errors and organising the interview transcripts in paragraph style before exporting the transcript into Nvivo 14 for auto coding.

The structural logic of this chapter is depicted below in figure 4.1. The diagram illustrates the presentation of data findings and analysis process in a structural format to graphically represent how the findings from each method were ultimately combined. Each phase is interconnected, ensuring that the findings are aligned with the research objectives, ensuring a cohesive and thorough data analysis.

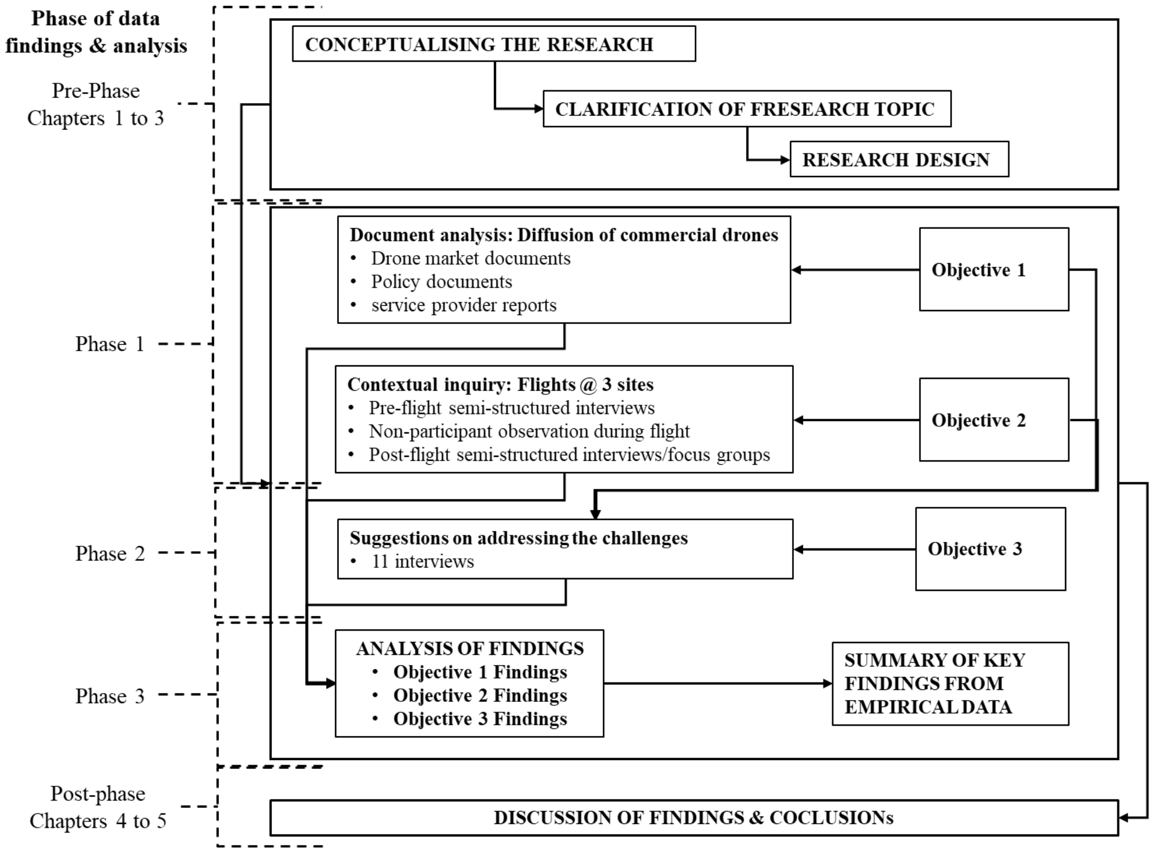

Figure 4.1: Structural logic of data findings & analysis

4.2. Document analysis

This section presents the data collected to ascertain the diffusion of commercial drones for construction related applications within the South African construction industry. Overall, 15 documents were retrieved as presented in table 4.1 and differentiated into three categories: (1) Drone market documents (table 4.2); (2) Policy documents (table 4.3); (3) service provider reports (table 4.4). Drone market documents were used to ascertain the nature of the South African drone industry. Policy documents were used to understand the impact of the regulatory environment on the accessibility of commercial drone market for the construction industry and the involvement of the piloting community in influencing the growth of the market. Service providers reports supplemented the evaluation of the extent of availability of commercial drones for certain sectors, particularly for construction-specific applications. Service providers reports also present an overview of engagements and proactive actions geared towards the development of a well-established drone economy in South Africa.

Table 4.1: Document selection

No	Documents selected	Institution
1	Part101 Regulations, 2015	SACAA
2	Amendment of Document SA-CATS 101 (Page 471-492) (17 March 2023)	SACAA
3	Rev Strategic plan for the Department of communications and digital technologies 2020 -2025 (31 March 2022)	Department of Digital Communication and Digital Technologies (DCDT)
4	Report of the Presidential Commission on the 4th Industrial Revolution, South African Government (23 Oct 2020)	Department of Digital Communication and Digital Technologies (DCDT)
5	South Africa Small Drones Market - Forecast (2020 - 2025)	Industry Arc
6	CUAASA and Department of Economic Development Drone Policy Dialogue	CUAASA
7	CEO Report, November 2023	Commercial Aviation Association of Southern Africa (CAASA)
8	Drone Industry Strategic Input: Towards the Drone Economy Masterplan, Version 11 (March 2021)	Drone Council of South Africa (DCSA)
9	Speech By Minister Stella Ndabeni-Abrahams, Minister of Communications and Digital Technologies, South Africa, Inaugural Drone Council Conference (15 July 2020)	Ministry of Communications and Digital Technologies South Africa
10	Global Construction Drone Market Forecast 2023-2030 (August 2023)	SkyQuest
11	Global Drone Market Report 2023-2030: New insights on the commercial drone market and an updated model for the drone market report (1 July 2023)	Drone Industry Insights (DroneII)
12	AATOSA President's Report 2023	(ASSOCIATION OF AVIATION TRAINING ORGANISATIONS OF SOUTH AFRICA) AATOSA
13	CUAASA Presidents Report for 2023	CUAASA
14	High Level Business Case for Drones Industry in the West Coast District (30 January 2022)	WESGRO Cape town & Western cape Research
15	Are you ready for the drone economy? By Dean Conde, UTM Lead, iOCO Digital (5 August 2022)	iOCO Digital

Table 4.2: Content analysis of selected documents

Cat	Doc	Data analysis				
		Context	**Codes generated**	**Inference**	**Targeted audience**	**Interpretation**
Drone Market documents	5	Commercial drone market in South Africa	Trends, application analysis, technology landscape, regulatory environment	Market growth patterns and drone application synergies	Investors, businesses, drone service providers, industry players, academia	Insights into current state and prospects of the SA commercial drone market
	9	Economic implications of commercial drone use	Advancement, applications, regulatory environment, industry collaboration, socio-economic	opportunities, challenges, and implications associated with drone tech integration into various aspects of society & economy.	policymakers, government, industry stakeholders, entrepreneurs, investors	Embracing tech advancement, importance of regulatory frameworks and industry collaboration
	10	Construction drone market share, and growth analysis	Market segmentation, advancements, trends	Market growth trend based on drone type and application	Industry professionals, investors, drone service providers	Insights into the expected growth trajectory of the construction drone market
	11	Commercial drone market, current state, trends, prospects.	Market size, application areas, trends, regulatory environment	Adoption drivers and competitive landscape	Industry professionals, investors, drone service providers	Comprehensive overview of commercial drone market for players in the drone ecosystem
	14	Extensive analysis of drone industry, focusing on SA	Industry growth, potential, regulatory environment, drone manufacturing, applications	Regulatory challenges, infrastructure & and potential to be a major player	Investors, drone service providers, government, academia	Potential for industry growth, acknowledging regulatory, infrastructural challenges.
	15	Participation in drone industry to capitalize on economic potential	Advancement, economic, regulatory environment, industry growth	Leveraging partnerships & innovation to drive economic growth	Government, industry stakeholders, investors	Prominence of drones across various industries and the significant growth forecasted for SA commercial drone industry.

Table 4.2: Continued

Cat	Doc	Data analysis				
		Context	**Codes generated**	**Inference**	**Targeted audience**	**Interpretation**
Policy Documents	1	SACAA guidelines ensuring safe & regulated flight operations within the country's airspace.	Aviation safety, training, certification, operational guidelines	Comprehensive approach to ensuring safety and efficiency of flight operations	Pilots, Drone operators, drone service providers	Detailed regulations governing flight training, skill tests, operator certificates.
	2	Amendment to drone regulations in SA	Safety, compliance, operational procedures, registration, airspace regulations, training.	Strict adherence to safety protocols, operational standard	Drone operators, aviation organisations	Reflect a concerted effort by regulator to adapt regulations and standard to foster growth while serving its mandate.
	3	Indication of government’s effort for economic growth through tech	Technological advancement, infrastructure development, socio-economic	Focus on leveraging technology to drive socio-economic development	General public	Insights into SA's efforts to leverage technology for socio-economic development
	4	Understanding emerging technologies to drive economic growth in SA	Digital transformation, innovation ecosystems, policy, regulation, socio-economic, collaboration	Technology adoption patterns, innovation ecosystem dynamics and the regulatory landscape	General public, civil society organisations, policy makers, service providers	Insights into the complex interplay of factors shaping SA's readiness for 4IR
	6	Addressing aspects of integrating drones across sectors.	Economic development, Regulatory, framework, collaboration, engagement	Recognition of evolving regulatory landscape and the necessity to adapt policies for growth	Government, industry stakeholders, policymakers	Comprehensive overview of a drone policy dialogue

Table 4.2: Continued

Cat	Doc	Data analysis				
		Context	**Codes generated**	**Inference**	**Targeted audience**	**Interpretation**
Service Provider reports	7	Addressing concerns relating to excessive regulation	Regulatory challenges, efficiency, growth, industry-regulator collaboration	Urgency/concern within aviation industry regarding need for regulatory reform & efficiency improvements	Aviation industry, regulators, associations, policymakers	Concerns about excessive regulation & potential negative impact on industry's competitiveness and growth prospects.
	8	Strategic input into development of SA digital economy master plan	Drone Industry transformation, drone economy,	Facilitation of barrier reduction and growth through determined action plans	Government, industry stakeholders, policymakers, investors, academia	Drone economy acceleration that promotes and support drone production& consumer economy.
	12	Collaborating with regulators address drone challenges	Collaboration/regulatory development/training	Ongoing efforts to streamline regulatory processes	Aviation professional, regulators, government	Achievements in regulation developments, licensing, RPAS training
	13	Representation of commercial drone operators' interests	Regulatory advocacy, collaboration, education & awareness, policy guidelines	regulatory reforms, addressing challenges related to licensing and certification	Commercial drone operators, regulators, insurers	Achievements in engagements to address commercial drone challenges.

As indicated in tables 4.2, 15 documents were analysed based on the context, present relationships and their interpretation to determine the state of the drone industry in south Africa. The analyses resulted in the categorization of these documents according to the three categories mentioned earlier. While 6 out of the 15 documents were identified as drone market documents, 5 out of the 15 documents were considered policy documents. The remaining 4 documents were classified under service provider reports.

4.3. Case studies

The case study field work was a contextual inquiry and comprised of three phases. The first phase was a set of semi-structured interview sessions where the researcher interviewed participants involved in construction site quality inspections undertakings. The second phase was the deployment of drone technology on the construction site. Here, the researcher observed certain difficulties expressed or experienced during the deployment of the drone technology to aid the quality inspection process. Lastly, the third phase was the follow-up interview phase where the researcher interviewed stakeholders that were involved in the process of carrying out construction site inspections with the aid of drone technology. Although the initial plan was to conduct individual follow-up interviews for all three cases, certain difficulties were experienced during the first case which prompted the switch from individual interviews to a focus group setting during the second and third case studies.

The interviews were conducted with the intention to identify perceived and experienced inherent challenges associated with the deployment of drone technology for construction site quality inspections. To maintain ethical standards of confidentiality, the participants are identified with codes. These codes are: C1P1, C1P2, C1P3, C1P4, C1P5 for participants who were involved in the first case; C2P1, C2P2, C2P3, C2P4 for participants involved in the second case; and C3P1, C3P2, C3P3, C3P4, C3P5, C3P6 for participants who were involved in the third case.

4.3.1. Case characteristics

A total of three visits were carried out for the data collection process due to time constraints. The study was carried out on three construction projects in Gauteng. As shown in table 4.3 below, the first and second case are of health care facilities and the third case is of an education facility. Table 4.3 presents the main features and the distinct characteristics of each project.

Table 4.3: Project features description

Case Study	Type of construction	Project type	Location	Level of complexity	Project Description
Case 1	Healthcare facility	Govern ment	Johannesburg west, Gauteng	Major	New or Replaced Infrastructure Asset
Case 2	Healthcare facility	Govern ment	Johannesburg North, Gauteng	Major	New or Replaced Infrastructure Asset
Case 3	Education facility	Govern ment	Johannesburg Central, Gauteng	Moderate	New Infrastructure Asset

Although these cases were selected from government projects with similar level of complexities, they showcase different site arrangements and construction typologies.

As presented in table 4.4 below, the drone-aided inspection activity in case 1 encompassed brickwork inspection (inspection of walls). Drone-aided inspection challenges explored in case 2 occurred during an inspection of the final inspection near project completion and case 3 investigated these challenges during a roof inspection process which included commissioning and waterproofing. One was conducted per site as shown in table 4.6 below with three flights carried out in case 1 and 3 and 4 flights in case 2. The DJI Mavic Pro drone was used across all three cases.

Table 4.4: Case description and data collection

Project & Location	Description of area of inspection	Inspection scope	Drone used	No of flights	Total flight duration	Participation
Case 1	Brickwork inspection/inspection of walls	1. Cavity walls; brick reinforcing; correct wall ties being used. 2. Brickwork is not built over expansion joints 3. Check brick perp joints are in a straight line where specified 4. Check joints are to specified thickness and courses built level 5. correct doorframes, lintels used. Is the minimum bearing achieved? 6. Check all doors, windows, are correctly fastened to brickwork 7. Check all doors and window frames securely strutted and square 8. Check all door frames fully grouted in 9. Check brickwork for plumbness, ± 5mm over 3 metres. 10. Check wall plates are true, level and bedded in 11. Check brick joints are correctly raked out	DJI Mavic Pro	3	70 minutes	C1P1: Drone Pilot (operator) C1P2: Co-pilot (Observer) C1P3: Construction manager C1P4: Site engineer C1P5: Project manager
Case 2	Near completion – final inspection	**Plaster inspection** 1. Have all expansion joints been cut back to substrate and neatly formed 2. Check that all draw boxes, plugs, switches are clear of any plaster blockages 3. Check that all plastering is straight, plumb and square. 4. Visual inspection carried out. Snags remedied.	DJI Mavic Pro	4	92 minutes	C2P1: Drone pilot (operator) C2P2: Site manager C2P3: Structural engineer (inspector) C2P4: Client representative (remote)

		5. Concrete finish according to standard 6. Any dimensions outside set tolerances? **Paint** 1. All wet trades de-snagged 2. All metal works properly primed 3. All ceilings, carpentry and joinery, wiring, glazing, 2nd fix services, floor finishes, are successfully completed **waterproofing** 1. Have all the parapets been sealed and capped? 2. Have all full-bore covers been painted and reinstated? 3. Have all gutters been cleaned, and rubble removed from the roof? 4. Have hail guards been installed as specified?				
Case 3	Roof detail: commissioning and waterproofing	1. Check that sheets are not damaged or the presence of white rust 2. Check that correct overhang is provided 3. Check that correct washers and fixings are being used 4. Check that cutting to hips and valleys is to specification 5. Check roof for alignment and damages to surfaces 6. Check that flashings are installed properly 7. Check that sheet overhang at eaves project one third into gutters 8. Check that stacked sheets are securely anchored	DJI Mavic Pro	3	70 minutes	C3P1: Drone Pilot (operator) C3P2: Co-pilot (Observer) C3P3: Construction manager C3P4: Site manager C3P5: Project manager (remote) C3P6: Architect (remote)

Table 4.5 below illustrates the steps and activities that were involved in the drone deployment process. Critical information regarding the construction site environment such as the site characteristics, building plans and the general outline of conditions of drone deployment was determined to aid in the development of an efficient inspection plan. Thereafter, the drone operator conducted an extensive assessment of the site to identify potential risk zones to ensure drone operations in accordance with the part 101 regulations and SA-CATS101 guidelines.

Once flight mission parameters were established, the pilot performed some checks on the equipment, completed the ground control station set up and provided the link of the video broadcast to the other participants. However, this feature was not available during the first case. After having considered all the above, the inspection process began. Stills and videos were captured while device performance, flight data, flight path compliance and data quality were being constantly observed.

Table 4.5: Drone deployment process

Phase 1: Construction site information review	General outline of conditions for the use of drone • To conduct drone-aided quality inspections • Visual inspection – videos & still images for photogrammetry
	Review of as-built plans, historical inspection reports. • For definition of flight patterns to be performed
	Characteristics of the construction site • Take cognizance of surrounding natural environment
	Point of interest (POI) identification • Evaluate local conditions of the site zone to be inspected
Phase 2: Site risk assessment	Safe zone for pilot • Identification of drone take-off and landing area
	Establish Security parameter. • Assess surrounding for obstructions, potential hazards. • Flight mission parameters
	Pilot risk minimisation.

Table 4.5: Continued

Phase 3: Drone pre-flight setup	Conduct thorough inspection of drone. • Inspect all hardware and software: • Check battery, remote controller, rotors, etc.
	Ground Control Station (GCS) setup Use the ground control software to create a flight plan
	Flight initiation • Initiate the flight command from GCS software interface. • Monitor drone's status and telemetry data to ensure stability and proper operation.
Phase 4: Drone-aided inspection	Conduct inspection using drone. (Consider weather conditions. E.g., wind)
	Capture overall inspection zone then close-ups of elements. • Types of visual data captured: e.g., still images, video
	Periodic checklist • Device performance, flight data, flight path compliance, data quality

4.3.2. Case study participants' demography

Background information

The following section outlines the demographic information of the participants involved in the case study. This is a crucial step because it allows the researcher to determine whether the participants can be considered experts in their field. According to (Hennink *et al.*, 2020) expert predictions are generally more accurate than those made by non-experts. Table 4.6 below presents the participants' background information which includes their job title, role, experience, highest educational qualification, work location (site or office based), their academic background, previous experience with drone technology, etc.

Table 4.6: Demographic information

Participants	Position	Experience (years)	Academic qualification	Work location	Academic background	Previous Experience with DT
C1P1	Drone operator	14	BSc (Hons)	Office	Mechanical engineering/ aviation	More than 300
C1P2	Trainee drone pilot	2	Diploma	Office	Aviation	Appx 50
C1P3	Contractor's project manager	12	BSc (Hons)	Site/office	Construction management	0
C1P4	Contractor's site manager	9	BSc (Hons)	Site	Construction management	0
C1P5	Client Project manager	18	MSc	Office	Project management	3
C2P1	Drone operator	14	BSc (Hons)	Office	Mechanical engineering/ aviation	More than 300
C2P2	Contractor's construction manager	8	BSc (Hons)	Site	Construction management	0
C2P3	Consultant engineer	15	MSc	Office	Civil engineering	0
C2P4	Client senior business analyst	20	MBA	Office	Business Administration	More than 200
C3P1	Drone operator	14	BSc (Hons)	Office	Mechanical engineering/ aviation	More than 300
C3P2	Trainee drone pilot	2	Diploma	Office	Aviation	Approx. 50
C3P3	Contractor's project manger	13	BSc (Hons)	Site/Office	Civil engineering	0
C3P4	Contractor's construction manager	7	BSc	Site	Construction management	0
C3P5	Client's project manager	16	MSc	Office	Construction project management	0
C3P6	Client's architect	22	MSc	Office	Architecture /Property development	13

Participant background information presented in table 4.6 above provides an overview of participants' roles, qualifications, where they are based in terms of work as well as their experience with drone technology. Based on the positions of the participants listed above, their roles were elucidated and categorized as shown in figure 4.1 below. The participants' professions fall into four main categories: Drone pilot, Contractor's Project coordinator, Client's Project coordinator, and Client representative (consultant). Hence, data from interviews were gathered from 2 drone pilots, 2 client project coordinators, 3 consultants acting as the client's representatives, and 5 contractor's project coordinators. Thus, the data provided incorporated perspectives from both contractors and consultants, ensuring a balanced and comprehensive dataset for the research.

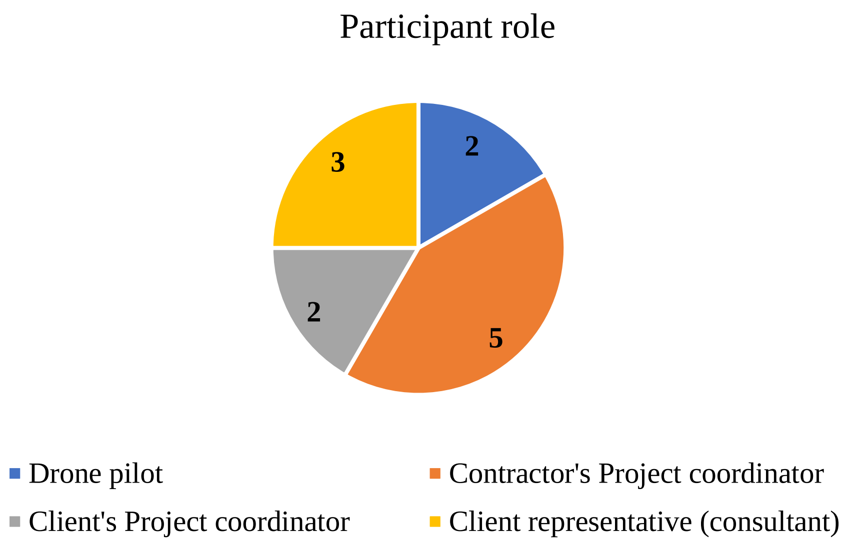

Figure 4.2: Case study participants' roles

The category of project coordinators interviewed is indicative that they are experts in the construction industry and are regularly involved in various inspection processes throughout a project's life cycle. Thus, they can be deemed to have provided appropriate and reliable data for this research. On the other hand, the participants' educational level plays a crucial role in this study as it can impact their answers. According to the data in Table 4.6, the majority of participants were BSc (Honours) degree graduates, making up 42%, while an equal percentage of participants held a master's degrees. Two individuals, accounting for the remaining 16% consist of one

BSc graduate and one diploma certificate holder. Thus, it is evident that the participants have achieved higher learning education and therefore provided adequate information.

The participants' years of experience, as shown in figure 4.2 below, also play a crucial role in this research as it is thought to impact their reasoning and judgment. The participants across the board have experience ranging from 2 to 22 years, with the trainee drone operator having the least experience. However, the average years of experience for the 12 participants is 13 years. Consequently, it is evident that the respondents possess substantial experience and, as a result, offered insightful responses for the research.

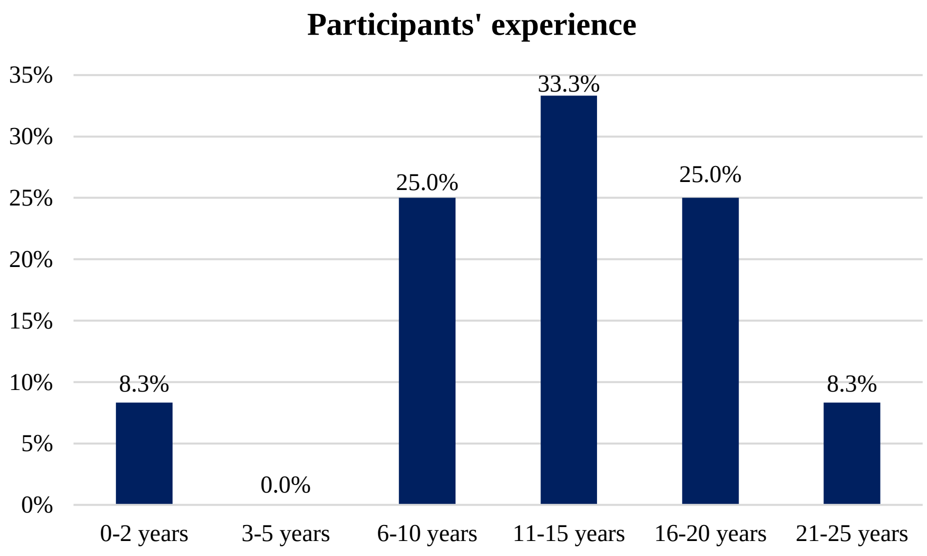

Figure 4.3: Case study participants' experience in their profession

In terms of experience regarding the number of projects where drone technology was used, two of the participants have experienced between 200 and 300 of such projects, one has been involved in approximately 50 projects, the other two participants in 13 and 3 projects respectively. However, 7 out of the 12 participants have never been involved in any project where drone technology was used.

4.4. Interview participants' demography

This section presents the demographics of the interviewees pertaining to the research objective 3. Individual interviews were carried out with semi-structured questionnaires used an instrument of solicitation. Table 4.7 below illustrates the demographic of the participants which includes their profession, geographic location, the sector of economy in which they function, years of experience as well as their level of knowledge with drone technology. A total of 11 participants out of the 15 who were purposively selected to participate in achieving this objective agreed to be interviewed, giving a response rate of 73.3%.

Table 4.7: Objective 3 participants background information

Participants	**Profession**	**Geographic location**	**Sector of economy**	**Experience (years)**	**Knowledge of DT**
O3P1	Drone pilot	Johannesburg	Private/Public	14	Very high
03P2	Aviation pilot	Johannesburg	Private	26	Very high
O3P3	Drone instructor	Ekurhuleni	Private	11	Very high
O3P4	Construction manager	Johannesburg	Private	12	Low
O3P5	Construction manager	Tshwane	Private	7	Low
O3P6	Project manager	West Rand	Public/Private	32	Average
O3P7	Senior business analyst	Johannesburg	Public	20	Very high
O3P8	Property development manager	Tshwane	Public	16	High
O3P9	Principal project manager	Johannesburg	Public	25	High

O3P10	Drone service provider	Tshwane	Private	12	Very high
O3P11	Contractor (CEO)	Johannesburg	Public	23	High

The 11 interview participants consisted of 2 construction managers, 2 project managers, 1 business analysist involved in government infrastructure delivery, 1 property developer, and 1 CEO who is a contractor. In terms of geographic location, majority (6 out of 11) of the participants are based in Johannesburg, 3 in Tshwane, one in Ekurhuleni, and 1 in the West rand. All these individuals are situated within the Gauteng province.

Regarding the sector of economy in which they function, 5 are in the private sector, 4 in the public sector working in the government department of infrastructure delivery and the remaining 2 indicated that they function in both sectors. This implies a balanced representation between the private and public sector which provided balanced data which can be generalised across the two sectors. Their years of experience range from 7 to 32 years, with the average years of experience being 18 years. Consequently, it is evident that the respondents possess substantial experience and, as a result, offered in-depth responses during the interviews. Furthermore, their knowledge of drone technology was also expounded, revealing that 5 out of the 11 individuals have very high level of knowledge of the technology while 3 are highly knowledgeable. One of the interviewees (a project manager) indicated being average in terms of their knowledge of drone technology while two construction managers indicated low levels of knowledge with the technology.

Therefore, the rating of the participants indicates that most of them consider their knowledge of drone technology to be above average. This indicates that their viewpoint on addressing the challenges hindering drone technology proliferation in the construction industry holds validity. Participants with low or average ratings were not disregarded, as their knowledge in drone technology and its applications surpasses that of the average individual. Furthermore, all participants who received low or average ratings have previous experience working on a project where drone technology was applied, which is why their opinions were considered.

4.5. Objective one: Diffusion of commercial drones within SA construction industry

The first objective of the study was to ascertain the level diffusion of commercial drones in south Africa, paying special focus to their applications relating to the construction industry. In using document analysis to address this objective, three key points emerged from the content analysis which were then framed into the following to aid in achieving the objective:

1. Evolution of commercial drones in South Africa
2. The market availability of commercial drones in South Africa
3. The current state of South Africa's drone industry

4.5.1. Evolution of commercial drones in South Africa

The evolution of commercial drones in south Africa can be attributed to the category drone market research. As presented in table 4.2 the codes generated within this category related to each other and in some way or another involve the past, present and future landscape of commercial drones in South Africa. Hence, from these codes and the context of each of the documents, the data could be used to generate the evolutionary timeline of commercial drones in South Africa as shown in figure 4.4. the literature reviewed was also used as a supplement to produce the key developments of military drones in South Africa. Hence these key developments were used to draw comparisons to key milestones regarding the evolution of commercial drones. This is because the data reveals that a rise in demand for military drones has been observed as a driver of growth for commercial drones [5,10,11].

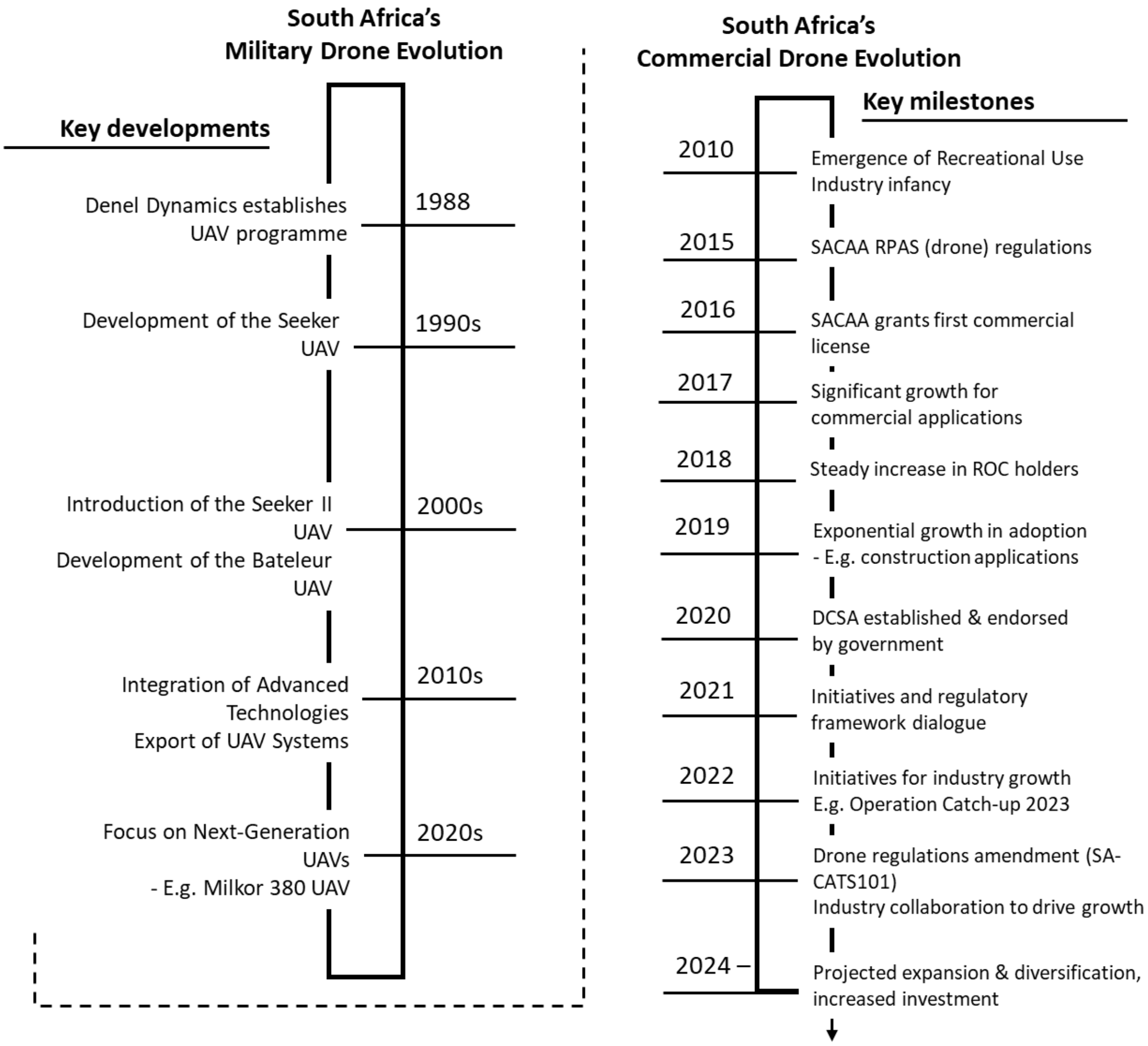

Figure 4.4: SA commercial drone industry evolution

<u>Drone economy transformation</u>

The codes such as trends, advancements, industry, growth, innovation ecosystems, generated under the can be grouped under one umbrella theme "drone economy transformation". The evolution of commercial drones from industry infancy in the 2010s to the projected expansions and diversification has been driven by advancements in technology and the growing trends in drones as tools which stem from a plethora of drone technology innovation ecosystems. Thus, the evolution of the drone industry in South Africa has led to the emergence of a robust drone economy which encompasses a wide range of activities including service provision, manufacturing and the development of infrastructure to facilitate drone operations.

Regulatory development advocacy

This is a recurring theme from the documents analysed based on the codes generated. From the documents categorised under drone market, "regulatory environment" appears in 5 out of the 6 documents. The frequency of this code in the documents highlights the theme regulatory development. Codes such as operational guidelines, training, policy guidelines, certification, safety which appear across policy documents and service provider reports are indicative of the theme regulatory development advocacy. In advocating for a supportive regulation framework, service providers and civil society organisations have made efforts aimed at the development of policies and regulations that support growth of the drone industry while ensuring safety and maintenance. This is evidenced by the amendment of the SA-CATS101 in 2023 which can also be attributed to industry collaborative initiatives as highlighted in the majority of the documents.

Summary of the evolution of commercial drones in SA findings

The documents analysed reveal that evolution of commercial drones in South Africa reflects a dynamic trajectory marked by innovation, regulatory adaptation, and increasing integration into various sectors of the economy. Other driving influences include initiatives from drone service providers and industry stakeholders who through collaboration with government agencies are fostering industry growth.

4.5.2. The market availability of commercial drones in South Africa

South Africa's commercial drone market segmentation

The commercial drone market can be segmented by type, size and application among other elements. In terms of type, fixed wing drones have gained significant market dominance due to their versatile applications in agriculture and large mining area mapping and surveillance. Fixed drones are known for their enhanced speed, increased payload capacity, and extended flight duration, which allows for increased survey areas per flight. However, multi-rotor drones are dominating the construction drone market due to their agility, operational simplicity with vertical take-off and landing VTOL, as well as excellent hovering and manoeuvrability. According to the data from [5,10,11], the ability of multi rotors to perform agile manoeuvres while maintaining visual contact with a designated target is anticipated to increase their demand for inspection, monitoring and surveying. The data also reveal that land surveying is the most dominating application within the construction industry. However, infrastructure inspection is the fastest growing under the application segment.

Segmentation of commercial drones by category reveal that drones for commercial applications can be classified into three main categories: beginner drones, advanced drones, and enterprise drones. Beginner drones are typically designed for casual data acquisition applications such as photography for marketing purposes. Enterprise drones offer more advanced features, better camera capabilities, longer flight times, and higher performance compared to beginner drones. They are suitable for commercial applications where more advanced functionalities such as data processing and analytics is required. Enterprise drones often come with specialized payloads, such as thermal cameras, LiDAR sensors, or multispectral cameras, and advanced features for mapping, surveying, and inspections.

Table 4.8 below provides a summary of the market segmentation presenting ten drone products that are widely available in South Africa. These drones are regarded among the best drones for applications in construction and infrastructure according to literature (e.g., Bayomi and Ferndandez, 2023; Choi et al, 2023). The drone product highlighted is the one used in the case studies under objective 2 as mentioned in section 4.3.

Table 4.8: Segmentation of top ten commercial drones for construction related applications

Category	Type	Product	Capabilities	Range	Endurance	Payload	Res
Beginner Drones	Multi-rotor	DJI Mini 3 Pro	Upgraded flight performance, stability, safety features Intelligent shooting modes	25km	47 Min	0.25kg	4K/38MP
	Multi-rotor	DJI Mavic Mini 2	Upgraded flight performance, stability, safety features Intelligent shooting modes	4km	31 Min	0.57kg	4K/12MP
Advanced Drones	Multi-rotor	DJI Mavic 3 Pro	Omnidirectional obstacle sensing AI-powered shooting modes	15km	46 Min	0.32kg	4K/5.1K/20MP
	Multi-rotor	DJI Air 2S	Advanced obstacle sensing & transmission technology Intelligent shooting modes	8km	31 Min	0.54kg	5.4K/20MP
	Multi-rotor	DJI Mavic Phantom 4	Advanced obstacle sensing system Intelligent flight modes	4km	30 Min	1.39kg	4K/20MP
	Multi-rotor	Autel EVO 2	Omnidirectional obstacle avoidance & AI-enhanced features for autonomous flight and tracking	9km	40 Min	1.1kg	6K
Enterprise Drones	Multi-rotor	DJI Mavic 2 Enterprise Advanced	Advanced imaging (thermal, 32x digital zoom) Enhanced safety/omnidirectional obstacle sensing Enhanced flight performance and stability	10km	31 Min	0.9kg	8K/24MP
	Multi-rotor	DJI Matrice 300 RTK	Triple-channel obstacle avoidance Advanced flight planning & control Weather resistant & hot-swappable batteries	8km	55 Min	6.3kg	8K/ 640x512 thermal
	Multi-rotor	Autel Evo 2 Dual	Dual thermal and visual cameras Omnidirectional obstacle avoidance	9km	40 Min		8K/ 640x512 thermal
	Fixed-wing	SenseFly eBee X	Precise georeferenced data collection Advanced flight planning & control	8km	90 Min	1.6kg	8K/24MP

Market drivers

Market report data reveal that technological evolution in hardware solutions, software and data processing coupled with decreasing costs, are poised to expand the range of potential drone applications and stimulate increased investment. Particularly, continuous enhancements in components that significantly influence their efficiency, safety, and reliability are expected to be key drivers for the growth of drone-powered solutions in the immediate future [10,11].

Opportunities for the construction industry

Recent advancements in sensor technology and onboard processing have unlocked focused aerial data collection capabilities suited to the multidimensional information requirements on construction sites. Currently, several drone service providers offer drone technology services that provide versatile and scalable platforms for integrating specialized sensor payloads such as LiDAR and multispectral sensors required for a variety of applications. Alongside drone hardware and software solutions, training and support services are a necessity to assist construction companies in adopting drone technology effectively [5,11]. Certified training providers offer courses on drone piloting, regulations, and best practices for construction applications. Additionally, drone service providers offer consulting, data analysis, and maintenance services.

Summary of the market availability of commercial drones in South Africa

Evidence from the document analysis indicates that the market availability of commercial drones for construction uses in South Africa is growing, with a range of drone models, accessories, and services adaptable for construction related applications. In essence, the synergy of market drivers, advancements in hardware and software technology, and increased accessibility positions drone technology as a transformative tool for various construction related applications.

4.5.3. The current state of South Africa's drone industry

South Africa's commercial drone legislative, regulatory & licensing environment

The legislative and regulatory framework and the government bodies that regulate drone operations are regarded as essential across all documents. However, based on

[6,7] it can be inferred that there is a sense of urgency and concern within the aviation industry regarding the need for regulatory reform and efficiency improvements. The findings suggest that current regulatory practices may hinder the industry's competitiveness and hinder its ability to attract investment and generate growth. There is a call for greater collaboration between the industry and regulators to address these challenges and promote a more conducive regulatory environment. However, the importance of adherence to regulations and standards in all aspects of aviation operations, including training, testing, certification, operations, and maintenance are still regarded as intrinsic.

From the detailed technical standards and requirements outlined in the amendments [2], it can be inferred that the regulatory authorities are keen on ensuring strict adherence to safety protocols, operational standards, and classification criteria for drone operators in South Africa. The consensus that regulatory landscape plays a crucial role in shaping the growth and development of the drone industry reflects a need for collaboration between industry stakeholders and government agencies in developing and refining regulatory frameworks to ensure safety, security, and responsible use of drones while balancing economic benefits and regulatory compliance.

Strategies to accentuate drone economy

The data reveals several key considerations and strategies related to the facilitation of large-scale adoption of drones, the futureproofing of drone regulations, leveraging drones for socio-economic benefits, addressing security and privacy concerns, and driving transformation within the drone industry. The major key consideration in the development of these strategies is the importance of establishing a regulatory framework that is operation-centric, risk-based, and flexible enough to accommodate technological advancements [8,9,3]. Emphasis is also made regarding the potential of drones to address socio-economic issues such as public sector services, job creation, and skills development.

Strategies are also geared towards addressing concerns regarding public acceptance of drones, particularly regarding security and privacy. This includes aligning training programs with aviation qualifications, increasing training capacity, knowledge transfer, and job creation initiatives [4,8]. Various stakeholders involved in the drone industry, including government agencies, regulatory bodies, operators, manufacturers, aviation organisations, educational institutions, and community groups are aim at to ensure the development of inclusive and effective drone economy that promotes and support drone production and consumer economy.

Summary of the current state of South Africa’s drone industry

Overall, the data paint a picture of an expanding industry with vast potential for growth and innovation, while also acknowledging the regulatory and infrastructural challenges that need to be addressed. It suggests that South Africa has the necessary ingredients to become a significant player in the global drone market but must overcome obstacles such as regulatory and investment constraints. The emphasis on leveraging demographic advantages and strategies underscores the importance of a holistic approach to industry development.

4.6. Objective two: Challenges to drone technology deployment

The second objective aimed to identify and outline challenges impacting the utilisation of drone technology for construction site inspections within construction projects, as perceived and experienced by project coordinators. This section outlines the empirical findings from the case study pertaining to the second objective.

4.6.1. Perceived challenges in attempting to implement drone technology for construction inspections

Participants were asked to indicate some challenges that they thought could hinder implementation of a drone-based approach. The question asked was answered by the 10 participants who are role players within the construction industry. The following perceived challenges were outlined by the 10 interviewees: Capital and resource allocation from owners (10 out of 10); Transparency and contractual accountability fears (7 out of 10); Value for money (7 out of 10); Contractor’s general lack of commitment to adopt efficiency improvement tools (6 out of 10; Inspections are seen as a leadership strength of the construction manager (5 out of 10); Organisational policies (4 out of 10).

Lack of capital and resource allocation from owners

Sufficient allocation of resources, including budget, personnel, and time, for training, equipment procurement, in order to implement drone technology was the most perceived challenge by the project stakeholders. While the project managers highlighted the general allocation of resources including budget, construction managers were also concerned about the personnel and training required before implementation.

The lack of decision makers to understand or envision the end result would be a major challenge in attempting to implement drone technology for inspections (C1P5, C2P3, C2P4, C3P3, C3P5;).

Owners may face competing priorities for allocating capital and resources within construction projects (C1P3; C1P4, C2P3, C3P6).

Owners may prioritise investments in traditional construction methods, equipment, or personnel over emerging technologies like drones, especially if they perceive these technologies as secondary or optional rather than essential for project success (C1P3, C1P5, C2P2, C3P4, C3P4, C3P6).

The general indication is that owners may be reluctant to allocate resources to implementation because they are unfamiliar with the capabilities and benefits of drone technology. They may lack understanding on how drones can improve project efficiency, safety, and data collection processes, which would justify the investment.

Transparency and contractual accountability fears

Drones introduce significant amount of data, including images, videos, and survey data. This information can be seen as sensitive information and disclosure may lead to certain consequences in terms of accountability (C1P2, C1P4, C1P5, C2P3, C3P4, C3P6).

Safety is paramount in drone operations, especially in construction settings where drones may be flying near workers, equipment, or structures. Drone operations on site introduces fears on companies being accountable and alliable for accidents involving employees related to drone use (C1P2, C1P3, C1P4, C2P3, C2P4, C3P3, C3P6).

The thought that the data captured could be used in a contractual dispute or claims situation may make the technology look like a liability equality to improving inspection depths. This is where the top guys might choose to be more risk averse and do things the normal way in fear of total transparency (C1P3, C1P5, C2P1, C2P3, C2P4).

Value for money

Seven participants were of the view that adopting drone technology requires an initial investment in purchasing the drones, sensors, software, as well as training personnel to operate the equipment effectively. They indicated that there might be hesitation to allocate significant capital upfront, especially if there are uncertainties about the return on investment or the long-term benefits of using drones.

Looking at the cost of bringing in the devices against the cost of the value would be a challenge, if inspections can be done in house it would mean less logistical stress to arrange and bring in a specialist drone operator (C1P3, C3P3).

It is very difficult to convince the people who think they are already spending too much to spend on a special tool. Some specific situation would either have to force them or some masterclass convincing (C3P5).

The general consensus is that project managers might be put off by looking at the value from drone technology as an intangible element of project management such as time.

"That is why they [projects] all always over time, because time is an intangible element in a way." (C1P4).

Owners operating within tight budget constraints may struggle to allocate additional funds for adopting drone technology, especially if they perceive it as an additional expense rather than a strategic investment. They may require clear evidence of cost savings, productivity gains, or competitive advantages before committing (C1P4, C2P2, C2P3, C3P3, C3P3).

Contractor's general lack of commitment to adopt efficiency improvement tools

The general lack of commitment among contractors to adopt efficiency improvement tools was highlighted as a significant challenge. The general consensus among (C1P3, C1P4, C2P2, C2P4, C3P4, C3P5) was that a lot of contractors are accustomed to traditional methods and may be hesitant to embrace new technologies.

"Contractors may perceive the adoption of efficiency improvement tools like drones as disruptive to their established workflows and processes." (C3P5).

Inspections are seen as a leadership strength of the construction manager

It seems the current approach to project delivery has positioned the construction management/site engineer role as a leadership role that possess *"the eye of an inspector"* as a quality trait/strength. Projects managers have entrusted daily and regular inspections to construction managers. Unless an inspection is mandated by local regulations or by the client, the contractor relies on the construction manager to deliver timely feedback which mainly covers reports detailing the status of the site environment, a major aspect of the inspection process. This means that the top project stakeholders are not specifically spending extra to conduct inspections.

Organisational policies

The project managers (C1P3, C1P5, C3P3, C3P5) indicated that organisational policies play a crucial role in guiding the behaviour, decisions, and operations within a company. When it comes to integrating drone technology into construction projects, several organisational policies may need to be re-established or adapted to ensure implementation. This may deter the thought of bringing in the technology.

4.6.2. Perceived challenges during deployment of drone-aided inspection

When asked what challenges they thought would arise during the deployment process on the construction site, technical complexity and disruption to site activities emerged as two major themes across all three case study participants.

Technical Complexity

The notion among both drone industry professionals and the project coordinators is that operating drones requires specialised skills and knowledge, including piloting, data collection, analysis, and interpretation. Construction managers may lack the technical expertise or resources to effectively integrate drones into their projects, leading to challenges in implementation and utilisation (C1P1, C2P2, C1P3, CP2P3, C2P4, C3P3, C3P4, C3P5).

Understanding the data produced and the processes involved might pose a challenge. It was highlighted that the site guys might struggle to assimilate with the technology as well without any prior training. (C1P1, C2P2, CP2P3, C3P3, C3P4, C3P6).

"*I think of drones as being part of the aviation industry. I know nothing about aviation, all I know is that it all seems too complicated for a no science person. The process might be too difficult for the construction guys to understand."* (C2P3)

"The technology seems too fancy, which is something that the top guys always avoid due to anticipation of provision of resources for learning." (C1P4).

<u>Disruption to site activities</u>

The presence of drones flying overhead was indicated as a possible cause of distractions or discomfort for workers, impacting their productivity and focus on tasks at hand (C1P3, C1P4, C2P2, C2P4, C3P3, C3P4, C3P5).

"Introducing drones into construction sites may disrupt ongoing activities due to the need for inspection zone clearance and safety protocols." (C1P3).

"Workers may need to pause or adjust their tasks to accommodate drone flights, leading to temporary delays or interruptions in site operations." (C3P4)

4.6.3. Major determents from wanting to implement drone-based approach

In answering the question relating to the resulting determent from wanting to implement a drone-based approach, lack of interest from key project stakeholders (8 out of 12); accessibility to drone technology (7 out of 12); and capacity issues (6 out of 12) were outlined as major deterrents from wanting to implement drone-based approach by the 12 interviewees

<u>Lack of interest from key project stakeholders</u>

The lack of interest from key project stakeholders poses a significant challenge to the implementation of drone technology in construction projects. Key stakeholders play crucial roles in decision-making and project execution. These stakeholders may lack interest or buy-in for integrating the technology into the project processes (C1P2, C1P3, C1P4, C2P2, C2P3, C2P4, C3P3, C3P4, C3P5).

Stakeholder disinterest may result in the reluctance to allocate resources towards implementing drone solutions as stakeholders who are comfortable with existing methods may be resistant to adopting new technologies, especially if they perceive the transition as disruptive or time-consuming (C1P2, C1P3, C1P4, C2P3, C2P4, C3P3, C3P4, C3P5).

Stakeholders may be put off due to concerns about the upfront costs involved in purchasing drones, training personnel, and integrating drones into project workflows. They may prioritise short-term cost savings over potential long-term benefits (C1P2, C1P3, C2P3, C2P4, C3P3, C3P4, C3P5).

Capacity issues

Capacity issues might impede continuous site inspections because of stakeholders' primary roles. The program needs built environment and engineering disciplines that would be particularly trained to become drone operators and would have access to drones when they need to use them. Alternatively, have a centralised team of purely trained drone operators who can provide the services to the different entities in organisation's project value chain. (CP1P1, C2P2, P2P4, C3P3, C3P4, C3P5).

Drone industry professionals highlighted that although the regulator has adequate capacity to license the new pilots who will be entering the industry in the near future, there is a lack of capacity in terms of the ability to help commercial operators in their efforts to absorb the new pilots. Due to a shortage of capacity at the SA CAA, the commercial sector is unable to experience the expansion that is necessary to recruit additional pilots (C1P1, C1P2).

Accessibility to drone technology

There is lack of training institutions with the requisite knowledge. The field of drone technology is relatively new and rapidly evolving. As a result, there is a scarcity of instructors and training providers with the necessary expertise and experience in drone operations.

“Currently, there is a deficit in training capacity available in the country” (C1P1)

Commercial drone operators in South Africa must hold a Remote Pilot License (RPL) issued by the SACAA. To obtain this license, individuals must undergo training from SACAA-approved training organisations, pass written exams, and meet other requirements. The process of obtaining certification adds to the demotivation for individuals and businesses seeking to make full use drone technology (C1P1, C1P2).

4.6.4. Observation findings

Table 4.9: Fieldwork Observation Data Collection Procedure

<table>
<tr><th colspan="2">Main Objective:</th><th colspan="5">To observe the nature & occurrence of challenges during drone deployment for drone-aided construction site inspections.</th></tr>
<tr><td rowspan="6">Drone-Aided Inspection Event Observation Sheet</td><td colspan="2">Brief description of challenges & occurrence</td><td>Challenge causation</td><td>Direct Immediate effects</td><td>Challenge Severity</td><td>Challenge frequency</td></tr>
<tr><td colspan="2">Data acquisition challenges
Low quality live visual data at certain intervals
Visual inconsistencies at some locations</td><td>Poor connectivity
Camera resolution, sensor accuracy</td><td>Remote participants</td><td>Moderate</td><td>2/3</td></tr>
<tr><td colspan="2">Data processing & analytics
Poor signal during live broadcast
No immediate generation of 3D model</td><td>No automated GCPs
Specialised software on large memory PC</td><td>No visual of 3D model
No real time deep analysis</td><td>Severe</td><td>3/3</td></tr>
<tr><td colspan="2">Ground control station disturbances
Site personnel struggling to stay clear of GCS in their works</td><td>High traffic on construction site</td><td>Interference with flight plan</td><td>Minor</td><td>2/3</td></tr>
<tr><td colspan="2">Flight in accordance with regulations
Constant visual contact with drone throughout inspection process</td><td>Site dynamics – operator had to fly drone without direct visual contact due to obstacles.</td><td>The drone operator had to operate BVLOS for a few minutes</td><td>Moderate</td><td>1/3</td></tr>
<tr><td colspan="2">Disturbance to site activities Personnel during deployment process</td><td>Personnel were disturbed by drone flying around site</td><td>Work stoppages, loss of concentration to task at hand</td><td>Moderate</td><td>3/3</td></tr>
</table>

Table 4.9 above presents the findings of challenges observed by the researcher during the deployment process. The frequency depicts the occurrence level of the challenges across the three cases. Severity depicts whether the challenges minor (impact on inspection process could be rectified immediately; moderate (impact would cause delay, but remedial measures available on site; major (considerate remedial action required was not possible on site); or sever (extensive measures were required to remedy the challenge).

Data Acquisition Challenges

Intermittent low-quality live visual data and visual inconsistencies at certain locations were observed in case 1 and case 3. These hindered the reliability of data acquisition, potentially leading to incomplete or inaccurate information about the inspected area.

Data Processing & Analytics

Poor signal during live broadcast and the absence of immediate 3D model generation delayed the interpretation and utilisation of collected data, limiting the real-time response to identified issues on the construction sites. This was observed in all three cases.

Ground Control Station (GCS) Disturbances

Disturbances at GCS, such as site personnel struggling to stay clear of GCS during their work was observed in case 1 and case 2. These disturbances can disrupt the drone's flight plan and compromise safety.

Flight in Accordance with Regulations

Adhering to regulatory requirements is paramount for safe and compliant drone operations. Maintaining constant visual contact with the drone throughout the inspection process is a regulatory mandate aimed at ensuring the safety of both the drone and surrounding airspace. However, it was a challenging for the drone operator to uphold in case 2 due to the complex site environment.

Disturbance to site activities

Disturbances to the site personnel as they were preforming their tasks was observed in all three cases. The flying around of the drone took the concentration of workers from their tasks. Although workers were briefed by their supervisor of the drone deployment, they still became curious. For the most part of the drone deployment their attention was fixated on the drone-aided inspection activity.

4.6.5. Challenges experienced during the drone deployment process

Participants were asked in a follow up interview (C1P1…C1P5) and in a focus group setting (C2….and C3…. participants) to indicate any challenges they experienced during the drone deployment process.

Connectivity issues

Connectivity issues (signal interference and network) resulted in interruptions and delays in data transmission, affecting the quality of the information received by those participants who were participating remotely (C2P4, C3P3, C3P6). C2P4 indicated that they experienced some degradation in video quality, including pixelation, blurriness, and buffering during the broadcast.

Battery life and inspection area

Another challenge was the drone in terms of the size and capacity it possesses. The drone could only fly 17 minutes per battery. Drone mapping requires covering the entire area of the point of interest of the site which required 2 to 3 batteries (combo set of a drone with 3 batteries fully charged).

Due to the number of flights in case 2, the site required more batteries, the operator had to charge the batteries while using drone. This created time delays and affected output because of shadows from the sun that may affect the map of the model. Certain portions were not visible.

"The best approach would have been to conduct the drone inspection late morning/early afternoon when the sun is at its highest." C2P1

Data quality

The reduction in data quality due to poor connectivity in case 2 more especially was indicated as having affected the participants' ability to discern important details from the video footage. Variations in lighting was also noted to have contributed to low data quality at some instances.

Volatile site environment

Some projects were volatile due to certain issues that have not been resolved. Because these are public infrastructure, there is vested interest from the community to participate in the project. There was a situation in case 3 where there was a stoppage during drone operations because of a dispute about employment and subcontracting issues from the surrounding communities.

"It becomes a security risk to operate the drone in case of a strike. We were only able to solve these challenges by coordination with the project team." (C3P4)

Ground control points & terrain

The type of drone (DJI Mavic 3 pro) used is an entry level industrial drone. It is not meant for pure industrial application.

"The one challenge with that is when you are performing an inspection and want to map the site and model it into a digital twin, there are certain additional resources that you need. For example, using the benchmark ground control points (GCP) from the construction site team." C1P1

The drone does not have the automatic capability to define ground control points to scale the model. Moreover, it takes much more experience to learn to maximise this type of drone's capabilities.

Processing time and rendering

The processing speed and efficiency were limited by the type of drone used. (C1P1). The lack of access to high-performance computing resources on the construction sites was also indicated as a contributor to processing challenges. The limited capabilities of the type of drone also meant that it was not possible to generate actionable 3D models and maps in real-time.

Software platforms compatibility

During the focus group discussions in case 2, project stakeholder indicated that they would have liked to incorporate drone data collection process into SnagR, a snags detection and recording app, for better and more centralized highlighting of nonconformances. However, the drone operator indicated that it is not possible as drone AI is not compatible with the SnagR app.

Rapidity in data collection

It was noted that there was no real-time evaluation of the elements that were being inspected. This was associated with the rapid level of data collection. There was very little time for proper qualitative analysis of the data from the live feed as it is being collected

"Video feed was just too fast for me to conduct any real-time evaluations or assessments of the components". (C1P4)

"To me it felt like the drone was being used as a tool for recording inspection data for assessments and analysis later" (C2P2)

Some participants (C1P3, C2P4, C3P3, C3P5) highlighted that they would have liked an option to zoom in on some areas or rewind the video feed to note key nonconformance noticed before they forgot.

"I would have to highlighted key issues I saw before I forgot or before I noted other issues". (C1P3)

"I would have liked more interaction between drone AI and myself as an inspector even though I am not the one operating the drone". (C3P3)

Determination of ground control station on complex site

Take-off and landing area need to be located in a secure or controlled area to prevent unauthorised access or tampering with drones during operations. Ensuring that this area is clear of obstacles and hazards to minimise the risk of collisions or accidents is very essential. Participants in case 1 emphasised that they experienced difficulties when determining a suitable area for take-off and landing.

It was a challenge on site to determine the take-off and landing area that could be cordoned off due to high site traffic (C1P1, C1P2, C1P3, C1P4).

4.6.6. Summary of the challenges experienced

The deployment process of the drone technology on the three construction sites were with some challenges which were experienced by the participants. Several challenges, including connectivity issues impacting data transmission quality, battery limitations causing operational delays, and volatile site conditions disrupting operations, poor connectivity and lighting variations compromise data quality, hindering effective analysis were recurring themes. Site complexity was also highlighted as having made it difficult to define ground control station, while limited processing capabilities and software compatibility of the drone type used were somewhat outlined as having impeded high quality real-time data processing.

4.7. Objective 3: Suggestions on addressing the challenges

The third objective was to suggest ways of tackling the identified challenges impeding drone technology application proliferation within the construction industry. The aim of this objective was to identify technological-organisational-external (environment) factors that address challenges hindering the optimal utilisation of drone technology for construction project related applications. The literature review identified challenges currently impeding the rise in the uptake of the technology. A case study method was used to collect empirical evidence identifying the nature and occurrence of the challenges during drone deployment on a construction site. This section presents empirical results from 11 interviews with drone industry professionals and construction industry professionals to achieve the third research objective.

Streamlined regulatory processes

This necessitates enhanced flexibility in the process governing requirements and the interaction between those applying and the authority to secure approvals. (O3P1, O3P2, O3P3, O3P10) were all of the view that applicable requirements should be determined through a risk-based approach, with a minimum set needed to qualify for certificates.

"The absence of a pilot on board drones highlights a significant departure from traditional manned aviation regulations, which are definitely not be suitable for regulating drones." (O3P2)

The categorisation suggests a risk-based approach for regulating drone operations, establishing a foundational regulatory framework to enable the standardisation of various aspects of drone operations through technical and operational initiatives. The regulatory strategy encompasses aircraft design, production, maintenance, operational approval, pilot competencies, however, safety and security in aviation. Indications were aligned with the following:

The categorisation would lower the bureaucratic barriers to entry and speed up the process of licensing issuing (O3P1, O3P2, O3P3, O3P10).

The creation of a regulatory space for ROC light certification for low-risk environments. (O3P1, O3P2, O3P3, O3P10)

Industry advocates for streamlining processes, specifying time frames, and cutting the costs (O3P1, O3P2, O3P3, O3P7, O3P10).

Therefore, streamlining of regulatory processes was alluded to being essential for unlocking the full potential of drone technology and fostering its widespread adoption across different sectors of the economy. More so by drone industry professionals. A crucial step towards creating a conducive regulatory environment that promotes innovation, entrepreneurship, and sustainable growth in the drone industry (O3P1, O3P2, O3P3).

Collaboration, co-operation & co-creation

Collaboration, co-operation and co-creation was coded as a theme relating to the involvement of major industry players in the dialogue within and outside their drone ecosystems. For example, with aviation organisations as they share the same airspace to advance unmanned aviation (O3P2, O3P10).

It was also noted that the SACAA and the drone industry has established a 'RPAS liaison committee' which serves as a collaborative platform between regulatory authorities and stakeholders involved in the operation and service provision of drones. This committee plays a vital role in facilitating communication, coordination, and cooperation among various entities with an interest in drone technology (O3P1, O3P2, O3P3, O3P10).

From the construction industry professionals, it was indicated that the drone programme implemented in the department of infrastructure was perceived as a policing mechanism by public project stakeholders because it was verifying or validating information projected by them.

"People did not warm up to it which became a challenge later on when we sought adoption for other use cases besides visual inspections and monitoring." (O3P7)

Collaboration and co-operation were indicated as mechanisms that would drive the conversation around drone technology and digital technologies, digital engineering as an approach and the various possibilities that are out there O3P4, O3P6, 03P7, O3P8, O3P9).

Proof of concept

Proof of concept by level 7-9 CIDB rated companies demonstrating successful use cases and contextually relatable scenarios of how drones have improved project outcomes was indicated as a suggestion that would highly mitigate implementation challenges and deterrence (O3P4, O3P5, O3P6, O3P8, O3P9).

For example, O3P6 stated that *"...conducting pilot projects or trials to showcase the practical benefits and ROI of drone technology in specific project contexts."*

Furthermore, (O3P4, O3P5, O3P6, O3P7, O3P8, O3P9) indicated that the proof of concept would aligning drone initiatives with broader project objectives, such as improving productivity, enhancing data-driven decision-making, or achieving sustainability goals, to demonstrate their strategic relevance and value.

Top management buy-in

From public sector project professionals, the consensus view was that drone programs need to be integrated to the various core services within the infrastructure delivery department or centralised in a particular unit of division that would then provide drone services to maintenance, property, construction, management, infrastructure delivery.

"At the moment it doesn't have clear sponsorship or buy in in terms of where it could be applied in the various services that we provide as the DID. The drones are still there but the project is not that active." (O3P7)

"Because we are a government entity, the change of administration and management personnel, shifted the priorities. The approach that was taken changed which meant that there was little buy-in from top management." (O3P9)

"The challenge that came in is that we would still gather information through drones, but the operations committee meetings were not happening as frequently as they used to. Eventually they stopped around the covid lockdown period." (O3P7, O3P8).

Training & education

One of the recurring themes under challenges was that there is lack of training institutions and suboptimal training capacity in the country. To address this challenge, it was outlined that there must be a national training footprint.

"We need to build the skills within our population so that people become familiar with drone technology." (O3P10)

"People must learn how to use these tools so that they know how to use them and are not afraid of them." (O3P3)

Designing comprehensive and relevant curriculum for drone training programs leading to new collar jobs (O3P2, O3P8).

"Drive the development of training schools in the more remote areas making Drone training accessible and inclusive…. transformation through training and developing black owned, run and managed profitable training organizations, SMMEs." (O3P8)

Majority of the construction industry professionals (4 out of 7) indicated that educating stakeholders about the benefits of drone technology and its potential applications can help foster acceptance and support for its integration into construction projects. Furthermore, ongoing education and upskilling initiatives can maximise the utility of drones in construction operations.

Overall, investing in training and education was highlighted as an important tool that can empower construction professionals to overcome challenges and leverage the full potential of drone technology for improved efficiency and productivity.

Top-down/bottom-up approach

The general consensus from private sector actors was that the most effective way to make the technology common place would be a top-down approach. However, the public sector actors indicated that most initiatives that are top-down do not bare fruits in the long run to due constant shift in top management personnel. Thus, they recommended a bottom-up approach where the operational stakeholders would be the one driving the technology.

"Maybe if the drone program was a solution that was more grounded in terms of operational personnel such as architects, engineers, QS's town planers." (O3P8)

"If these professionals were key stakeholders that wanted a solution to the problems that they were coming across that drone technology could assist to fast-track their work and improve the services that they provide. I think the program would still be active; they would see more value out of it". (O3P7)

"For me it's the perception that was there post the operations where we did the information gathering, there was a sense of mistrust. Maybe if it was bottom-up the picture would be different because they would be driving the use case." (O3P9)

For those private sector construction professionals (O3P4, O3P5, O3P6) the project was deemed effective because it came down from top-down approach from executive management, highlighting drone technology as tool they could use as an additional layer of information to verify reported information by project managers and the business intelligence systems.

Value proposition

The value proposition of drone technology for construction industry professionals lies in its ability to revolutionize various aspects of construction projects, enhancing efficiency, safety, and cost-effectiveness.

From the GDID interviewees (O3P6, O3P7, O3P8, O3P9, O3P11) the overall indication was that there was value in terms of keeping tracks with the number of projects that they had. Dealing with capacity issues in terms of managing service providers working on these projects.

"We were able to have a visual interpretation of works on site unlike before where it was in black and white." (O3P6)

*"The drone technology gave a different angle to how we were viewing things. This was a game changer." (*O3P7)

Drone industry niche

Across the board, 9 out of the 11 participants indicated that South Africa must identify a way to encourage the expansion of drone service provision (e.g., drone manufacturing) in order to lessen the costs associated with bringing in the technology. South Africa has developed and is developing several leading solutions in the drone arena (O3P1, O3P2, O3P3). To produce an abundance of more world-class products and solutions, it is necessary to provide an environment that promotes the growth, development, and maturation of drone solutions (O3P1, O3P2, O3P3, O3P4, O3P5, O3P6, O3P7, O4P10, O3P11).

From the indications, it is evident that drone industry professionals suggested ways of addressing related challenges based on the need for efficient service provision, while construction industry professionals' suggestions were influenced by the need for service consumption. However, implications were made by construction industry professionals suggesting efforts for 'in-industry' drone technology ecosystems.

<u>Summary of suggestions to address the identified challenges</u>

Overcoming challenges in the implementation of drone technology in construction requires a comprehensive approach by both construction industry professionals and drone industry professionals. Streamlining regulatory processes, such as adopting a risk-based approach and fostering collaboration between industry stakeholders and regulatory authorities, is essential to facilitate drone adoption and operation. Demonstrating proof of concept through successful use cases and aligning drone initiatives with broader project objectives can enhance the strategic relevance and value of drone technology. Investing in training and education initiatives to address skill shortages and involving operational personnel in decision-making processes can empower construction professionals to leverage drones effectively. Ultimately, by addressing regulatory hurdles, demonstrating tangible benefits, investing in skills development, and adopting inclusive decision-making processes, full potential of the technology can be realised.

4.8. Chapter summary

In this chapter, the findings of the document analysis and the case study were given. The case study included interviews, observations, and follow-up interviews. Furthermore, through interviews, professionals from the construction industry and the drone industry were asked to recommend strategies to solve the obstacles that are preventing the widespread deployment of drones in the construction industry. Both the background information of the participants and the features of the cases were described. Based on the results of the thematic content analysis that was performed on the data that was acquired, the most major challenges that stand in the way of the incorporation of drone technology into South African construction projects were also given, along with some solutions for overcoming these challenges.

The key findings from the empirical data indicate several important trends and challenges in the use of commercial drones in South Africa's construction industry. The documents revealed a dynamic growth trajectory, driven by innovations, regulatory efforts, and collaboration between industry stakeholders and government. The market for construction-related drones is expanding, offering various adaptable models and services. However, challenges such as regulatory hurdles, connectivity issues, battery limitations, and site complexities hinder optimal drone deployment. Suggestions on overcoming these hindrances relate to comprehensive approaches involving regulatory reforms, investment in skills, collaboration between industry and government, and demonstrating tangible benefits through successful use cases to unlock the technology's full potential.

All results in this chapter will be further discussed in the subsequent chapter.

CHAPTER 5: DISCUSSION OF FINDINGS

5.1. Introduction

Chapter 4 presented the findings and analysis based on the empirical data collection process. This chapter discusses these findings in relation to the findings from the review of extant literature, making reference to the DOI-TOE framework conceptualised in section 2.7. The chapter is organised according to the research questions. Therefore, a detailed discussion is provided to the key research findings with reference to each research question. The findings are discussed according to the following research questions:

1. *What is the diffusion of commercial drones for construction related applications within the South African construction industry?*
2. *What is the nature and occurrence of challenges to drone technology deployment for drone-aided inspections during construction execution stage of projects in South Africa?*
3. *How can identified challenges impeding optimal utilisation of drones during the execution stage of construction projects be addressed?*

5.2. Research Question one

What is the diffusion of commercial drones for construction related applications within the South African construction industry?

This question pertains to the maturity level of drone technology within the construction industry. The objective was to ascertain the current diffusion status of drone technology in South Africa, with a particular emphasis on its applications and trends within the construction industry in order to answer the question. The data analysis suggests evidence of use of drone technology in the construction industry, specifically in construction project applications.

From the literature review the application of drone technology in construction project management emerged as a significant trend driven by its efficiency, safety benefits, and capabilities in accessing difficult or hazardous areas (Golizadeh *et al.*, 2019; Falorca *et al.*, 2021).

The literature review also identified the applications of drones across various stages of the project life cycle, including pre-construction tasks such as site surveying, mapping, and planning, where they offer advantages over conventional methods like total stations and GPS devices (Yildizel snd Calis, 2019; Jiang et al, 2020; Albeaino and Gheisari, 2021). Quality control, project monitoring, inspections, and site security surveillance were aspects of the construction phase, where authors such as Mertinez *et al., 2021* and Nooralishahi *et al.,* (2021) identified that drones play crucial roles. Post-construction applications including building maintenance inspections, façade, and roof inspections across residential, commercial, civil infrastructure, and industrial projects showcasing the versatility of drones in different project contexts were highlighted by Ruiz *et al.,* (2021) amongst others.

The findings from the document analysis presented in section 4.6 provide a comprehensive overview of the evolution, market availability, and current state of South Africa's drone industry. The evolution of commercial drones in South Africa is depicted as a dynamic trajectory influenced by regulatory adaptation and increasing integration into various sectors of the economy. The market availability of commercial drones is characterised by segmentation based on type, size, and application. Furthermore, drones can be categorised into beginner drones, advanced drones and enterprise drones based on capabilities.

Regulatory development advocacy emerged as a recurring theme, indicating the industry's efforts to foster growth through supportive regulation while ensuring safety and compliance. Authors such as Nkamisa, Abrahams and Thukani, (2021) and Mokoena *et al.,* (2022) outlined the regulatory landscape and the governance of drone operations in South Africa. However, the document analysis discovered the amendments to RPAS regulations that were outlined in literature which showcases the rapid developments aimed at improving the state of the drone industry. The current state of South Africa's drone industry underscores the importance of legislative and regulatory frameworks in shaping industry growth.

5.3. Research question two

What is the nature and occurrence of challenges to drone technology deployment for drone-aided inspections during construction execution stage of projects in South Africa?

This question seeks to determine the nature and occurrence of challenges associated with drone technology deployment in construction projects. Hence, the second objective was derived from this question: To determine the nature and occurrence of challenges to drone technology deployment for drone-aided inspections during construction execution stage of projects in South Africa. Studies such as Albeaino and Gheisari, (2021) and Liang et al (2023) provided a roadmap for researchers to better understand suboptimal implementation of drone technology in construction projects. Therefore, the data analysed and listed in section 4.6 determines the challenges to the deployment of drones in construction projects for construction site inspections in the South African context.

One significant perception is that there would be a lack of capital and resource allocation from owners, which includes budget, personnel, and time required for procuring drone technology services. Concerns regarding transparency and contractual accountability were raised with the disclosure of sensitive information cited as something perceived could add complexity to the implementation process. Another challenge is demonstrating the value for money in adopting drone technology. It was noted that project managers may hesitate to allocate capital upfront without clear evidence of the return on investment or long-term benefits. Additionally, contractors' general lack of commitment to adopting efficiency improvement tools presents a significant hurdle. Furthermore, the reliance on construction managers for inspections, seen as a leadership strength, further complicates the integration of drone technology into construction projects.

During the deployment of drone-aided inspections, technical complexity and disruption to site activities emerged as major themes. Literature review revealed that operating drones requires specialised skills and knowledge, which construction managers may lack, posing challenges in understanding the data produced and the associated processes (Nwaogu *et al.,* 2023). Furthermore, the presence of drones flying overhead caused distractions for workers and disrupted ongoing activities, impacting productivity and site operations. In addition to implementation challenges, several deterrents that impede the adoption of drone-based approaches were outlined. The lack of interest from key project stakeholders, including owners and contractors, was cited as a significant impediment. Capacity issues, such as training constraints and regulatory limitations, were indicted as something that could impede continuous site inspections, as there may be a shortage of organisational personnel dedicated to the implementation of drone-based processes. Furthermore, accessibility to drone technology was stated by drone service providers to be limited by the scarcity of training institutions and instructors with the expertise in drone operations, coupled with regulatory requirements for certification, which may hinder broader adoption.

Likewise, connectivity issues, such as signal interference and network disruptions, were experienced hinderances to data transmission, impacting the quality of information received remotely and leading to degradation in video quality (Albeaino *et al.,* 2019). Moreover, limitations in battery life posed a constraint, necessitating the use of multiple batteries and causing delays during operations, especially when charging was required on-site. This limitation was a common occurrence in the reviewed literature.

Data quality was compromised due to poor connectivity and variations in lighting conditions, making it challenging for participants to discern crucial details from video footage. The volatile nature of construction sites, coupled with unresolved issues and community disputes, introduced operational disruptions, requiring close coordination with project teams to address security risks and ensure smooth drone operations. Furthermore, challenges in defining ground control points for scaling drone models, limited processing capabilities, and software compatibility issues impeded data processing and analysis, hindering the effectiveness of drone-based inspections.

5.3.1. Perceived challenges in implementing drone technology

Lack of capital and resource allocation from owners

Allocating sufficient resources, including budget, personnel, and time, for training and equipment procurement, was identified as a significant challenge. Project coordinators have highlighted the importance of having adequate resources, including budget allocation, personnel, and time, to effectively integrate drones into construction projects. However, they also indicated that owners may prioritise investments in traditional construction methods due to a lack of familiarity with the benefits offered by drone technology.

Allocating resources for equipment procurement is essential to acquire drones, sensors, and software necessary for conducting inspections (Zainudin, 2018). Despite the potential benefits of using drones for construction site inspections, owners may be hesitant to invest in this technology. Traditional construction methods may seem more familiar and reliable to owners, leading them to prioritise investments in these areas. As a result, securing adequate resources for implementing drone technology becomes a challenge.

Transparency and contractual accountability fears

Concerns about data sensitivity and safety accountability arose due to the significant amount of data drones collect. Disclosure of such data may lead to accountability issues and potential consequences in contractual disputes. Project coordinators have expressed concerns about the sensitivity of the data collected by drones during inspections, as well as the potential implications for safety accountability and contractual disputes. The substantial amount of data captured by drones, including images, videos, and survey data, raises questions about how this information should be managed, shared, and disclosed (Bayomi and Fernandez, 2023).

The data captured during inspections may serve as critical evidence in resolving disputes related to project performance, quality, or compliance. However, the disclosure of sensitive information obtained through drone inspections could also expose project stakeholders to accountability issues and legal liabilities. Furthermore, the fear of being held accountable for accidents involving employees related to drone use may discourage project stakeholders from fully embracing this technology.

Value for money

Project managers must carefully evaluate the cost-benefit ratio of investing in drone technology. They need to assess whether the potential benefits, such as improved efficiency, enhanced safety, and better data collection capabilities, justify the initial expenditure. However, without clear evidence of the return on investment, project managers may hesitate, especially if they perceive the benefits of using drones as uncertain or intangible (Devers, 2019).

Contractor's general lack of commitment to adopt efficiency improvement tools

The resistance among contractors to embrace new technologies like drones was also identified as a significant challenge. The notion among project coordinators was that contractors may perceive these tools as disruptive to their established workflows and processes. Contractors often operate within well-established procedures and workflows that have been refined over time to optimise efficiency and productivity (Al Nasseri and Aulin, 2016). The introduction of new technologies, such as drones, may disrupt these established workflows and require contractors to adapt their processes to accommodate the new tools. This perceived disruption can lead to resistance and reluctance to embrace the adoption of drones for construction site inspections.

Inspections seen as a leadership strength of construction managers

Traditional approaches have positioned construction managers as leaders in inspections. This reliance on construction managers for inspections was a perceived hinderance to the adoption of drone technology. The perception of inspections as a leadership strength of construction managers presents a unique challenge to the adoption of drone technology within construction projects (Mahmood, 2020; Martinez *et al.*, 2020). Traditionally, construction managers have played a central role in conducting inspections, leveraging their expertise to ensure quality and compliance on construction sites. Construction managers are typically responsible for overseeing daily operations, ensuring adherence to project specifications, and providing timely feedback on site conditions.

Organisational policies

Organisational policies play a crucial role in guiding decisions and operations (Aghimien *et al.,* 2022). Adapting policies to integrate drone technology may pose challenges, potentially deterring its implementation. Organisational policies are designed to ensure compliance with regulatory requirements, mitigate risks, and maintain operational efficiency. Adapting these policies to integrate drone technology requires careful consideration of various factors, including safety protocols, data management procedures, and personnel training requirements (York *et al.*, 2020). One of the primary challenges in adapting organisational policies to integrate drone technology is the need to incorporate protocols for drone operations.

5.3.2. Perceived challenges during deployment of drone-aided inspection

Technical complexity

Operating drones requires specialised skills and knowledge, to pilot effectively, collect accurate data, and interpret the results, which construction managers may lack. Understanding the data produced by drones and the associated processes may also pose challenges (Golizadeh *et al.*, 2019). Participants perceived the technical complexity associated with operational process to present a major challenge during the deployment of drone-aided inspections. Construction managers, who did not have prior experience or training in drone operations, thought they would find it challenging to navigate the intricacies of drone technology. Furthermore, they thought understanding the data produced by drones and the associated processes would add another layer of complexity.

Disruption to site activities

Another challenge that was perceived was the disruption to site activities caused by the presence of drones flying overhead. Perceptions from the interviewees was that drones, while performing their inspection tasks, would cause distractions for workers and disrupt ongoing activities on the construction site. This disruption can have a direct impact on productivity and overall site operations. This notation was also highlighted in literature (Rakha and Gorodetsky, 2018).

The noise and visual presence of drones flying overhead draws the attention of workers away from their tasks, leading to decreased focus and productivity (Fan and Saadeghvaziri, 2019). Workers could be curious or concerned about the drones, causing them to stop work temporarily or become less efficient in their duties. According to the literature reviewed, for example Fan and Saadeghvaziri, (2019), the movement of drones overhead may create a sense of discomfort or unease among workers, further contributing to distractions and disruptions on the site.

5.3.3. Major deterrents from implementing drone-based approach

Lack of interest from key project stakeholders

The lack of interest from key project stakeholders poses a significant challenge to the implementation of drone-aided inspections. Stakeholders, including project owners, managers, and decision-makers, play crucial roles in shaping project outcomes and determining the adoption of new technologies (Onososen *et al.,* 2023). However, it was noted that they may exhibit resistance to embracing drone technology due to various factors, including a preference for familiar methods, concerns about cost, and a focus on short-term savings.

Capacity issues

Capacity issues, including training and regulatory constraints, may impede continuous site inspections. There may be a shortage of trained drone operators and regulatory capacity to accommodate new pilots entering the industry. There is a need for individuals with expertise in the built environment and engineering disciplines to be trained as drone operators. These professionals must not only possess technical knowledge but also have access to drones when required for site inspections. Alternatively, organisations may opt to establish a centralised team of trained drone operators to provide inspection services across different project entities within the organisation's value chain. However, this approach requires careful planning and coordination to ensure timely and efficient deployment of drone resources (York *et al.*, 2020).

Furthermore, regulatory capacity plays a crucial role in addressing capacity issues within the drone industry. While regulators may have the ability to license new pilots entering the industry, there is a shortage of capacity to support commercial operators in absorbing these new pilots effectively. Literature review highlighted this shortage, particularly within organisations like the SA CAA (Mokoena *et al.,* 2022), citing the impediment on the expansion of the commercial sector, specifically the recruitment of additional pilots.

<u>Accessibility to drone technology</u>

The scarcity of training institutions and instructors with expertise in drone operations, coupled with regulatory requirements for certification, were indicated by drone service providers as key variables hampering accessibility to drone technology. Accessibility to drone technology is hindered by a lack of training institutions equipped with the necessary expertise. The field of commercial drones in South Africa is relatively new and rapidly evolving, leading to a scarcity of instructors and training providers with the requisite knowledge and experience in drone operations. This shortage of qualified trainers contributes to a deficit in training capacity, making it challenging for individuals and businesses to access comprehensive drone training programs (Mokoena *et al.,* 2023).

As highlighted in literature, commercial drone operators are required to hold a Remote Pilot License (RPL) issued by the SACAA. However, obtaining this license involves undergoing training from SACAA-approved organisations, passing written exams, and meeting other stringent requirements. (Mokoena *et al.,* 2022) expressed that the certification process adds further complexity and demotivation for individuals and businesses seeking to fully utilise drone technology.

5.3.4. Observation findings

The findings outlined in Table 4.9 highlight several challenges observed by the researcher during the deployment of drone-aided inspections across the three distinct cases. One notable challenge relates to data acquisition, where intermittent low-quality live visual data and visual inconsistencies were observed in certain instances, compromising the reliability of data acquisition and potentially leading to incomplete or inaccurate information about the inspected area. Similarly, issues with data processing and analytics were prevalent across all cases, with poor signal during live broadcast and the absence of immediate 3D model generation delaying the interpretation and utilisation of collected data, thereby limiting the real-time response to identified issues on construction sites. Ciampa et al., (2019) and Alvares et al., (2018) also noted similar issues in practice. Ground Control Station (GCS) disturbances, such as site personnel struggling to stay clear, were observed, posing risks to the drone's flight plan and overall safety.

Furthermore, compliance with regulatory requirements, especially maintaining constant visual contact with the drone, proved challenging due to the complex site environment in one case, emphasising the importance of navigating site-specific challenges for safe and compliant drone operations. Moreover, disturbances to site activities were widespread, as the presence of the drone often drew the attention of site personnel away from their tasks, despite supervisor briefings, highlighting the need for effective communication and engagement strategies (Freimuth and Koninng, 2018).

5.3.5. Challenges experienced during drone deployment process

The challenges encountered during the deployment of drone technology in construction projects shed light on various operational and logistical constraints faced by the participants. Connectivity issues emerged as a common challenge across the cases, affecting data transmission quality and remote participation. Battery limitations posed some hindrance, particularly in covering extensive inspection areas, necessitating efficient battery management strategies to mitigate delays and maintain output quality. Data quality concerns, exacerbated by connectivity issues and lighting variations, underscored the importance of stable connections for reliable data collection. Volatile site environments, marked by unresolved disputes and community involvement, posed security risks and operational disruptions, emphasising the need for effective coordination and conflict resolution strategies.

Furthermore, ground control points and terrain complexity posed technical challenges, especially with the entry-level industrial drone lacking automatic capabilities for defining ground control points, impacting the accuracy of mapped models. Processing delays and rendering inefficiencies hindered real-time data analysis and 3D model generation, pointing to the need for fit-for-purpose drone tools. Incompatibilities between drone AI and existing software platforms posed integration challenges, necessitating advancements in technological compatibility. However, rapid data collection posed challenges for real-time evaluations, highlighting the importance of enhanced data interaction and accessibility features. Additionally, determining suitable ground control station for take-off and landing proved challenging in a complex site environment.

The challenges experienced during the drone deployment process encompassed various aspects critical to the success of the operations:

<u>Connectivity issues</u>

The challenge of connectivity issues involved signal interference and network problems, leading to interruptions and delays in data transmission. This issue particularly impacted remote participants, affecting the quality of information they received. This challenge underscores the importance of robust communication infrastructure for effective drone operations, especially in remote or challenging environments (Asadi *et al.,* 2020; Rakha and Gorodetsky, 2018).

<u>Battery life and inspection area</u>

Drone battery life and the size of the inspection area posed challenges. Limited flight time per battery required frequent battery changes, leading to time delays, and affecting output quality, especially in areas with complex terrain and shading issues.

However, the limitations with battery life were discovered in the plethora of literature. Authors such as Falorca *et al.,* (2021), Golizadeh et al, (2019) and Irrizary and Costa (2021) noted this challenge as a common occurrence. Others such as Alsamarraiea *et al.,* 2022 who conducted systematic reviews also highlighted the limitations in endurance.

Poor data quality

Poor connectivity and variations in lighting conditions contributed to reduced data quality, hindering participants' ability to discern important details from video footage. Morgenthal *et al.,* (2019) and Tan *et al.,* (2021) suggested that ensuring consistent and reliable data acquisition is crucial for accurate analysis and decision-making. Improving network infrastructure, using drones with enhanced imaging capabilities, or implementing post-processing techniques to enhance data quality may be necessary to ensure high quality data collection.

Volatile site environment

The volatile site environment, characterised by unresolved issues and community involvement, led to disruptions and stoppages in drone operations. Disturbances to project activities by local community is a commonality across South Africa. The participants associated these disruptions with the high rate of unemployment in the country. The document analysis revealed that drone industry players plan to contribute to the economy by creating new collar jobs. Though this may not be relevant to address community concerns and minimise project disruptions in this regard, drone economy is intended to play a crucial role in addressing the country's socio-economic issues.

Ground control points & terrain

Technical challenges related to ground control points and terrain complexity affected the accuracy of mapped models. Due to the entry-level drone lacking automatic capabilities for defining ground control points required, additional resources were required for accurate data collection and analysis. Asadi *et al.,* (202) discussed the operational challenges in deploying drones, including issues related to GCPs and terrain variability, while Albeaino *et al.,* (2019) highlighted the importance of GCPs for accuracy.

Processing time and rendering

Limited processing speed and efficiency, compounded by the lack of access to high-performance computing resources on construction sites, prevented real-time generation of actionable 3D models and maps. Drone operators indicated that cloud-based processing solutions, optimising data processing workflows, or opting for a more capable drone could be an alternative option.

Similarly, previous studies pointed out the relationship between the type of drone used and the level of efficiency in terms of processing time, and rendering capabilities (Choi et al, 2023).

Software platform compatibility

Incompatibility between drone data collection processes and existing software platforms hindered centralised data management and nonconformance highlighting. Compatibility between drone system software and current ICT systems (such as the SnagR app mentioned) is crucial in ensuring smooth integration of drone technology into organisational workflows (Hanson and Olsson, 2020).

Rapidity in data collection

Rapid data collection presented challenges for real-time evaluation and qualitative analysis, with participants expressing the need for features such as personalised zooming and rewinding during live feeds to capture key nonconformances effectively. Participants indicated that improving user interfaces and implementing interactive features could enhance usability and effectiveness of drones as tools for quality inspection data collection. A similar issue was discussed in Albeaino *et al.*, (2019) where high-resolution cameras with zooming capabilities were recommended to enhance degree of image details.

Determination of ground control station on complex site

Challenges in determining suitable ground control stations, particularly for take-off and landing areas, underscored the importance of secure and obstacle-free zones for operational efficiency. Intrinsically, effective planning and coordination are essential to ensure the safe and efficient deployment of drones in construction projects (Hammad *et al.*, 2021).

5.3.6. Summary of drone implementation challenges

The challenges impeding proliferation in drone-aided inspections in South African construction projects as discussed above can be grouped into three categories in accordance with the conceptual framework developed in section 2.8. Table 5.1 below shows the groupings of these challenges into technological, organisational, and environmental aspects. Furthermore, the table stipulates the challenges in relation to applicable sources from previous chapters and in terms of occurrence.

Table 5.1: Categorisation of challenges (from the study)

Category	**Challenges**	**Literature**	**Perceived**	**Observed**	**Experienced**	**Total**
Technological	Connectivity issues	x			x	2
	Battery life and inspection area	x			x	2
	Poor data quality				x	1
	Processing time and rendering			x	x	2
	Software platform compatibility	x			x	2
	Rapidity in data collection				x	1
	Technical Complexity	x	x			2
	Ground control points & terrain				x	1
Organisational	Disturbance to site activities	x	x	x		3
	Lack of capital and resource allocation from owners		x			1
	Transparency and contractual accountability fears		x			1
	Value for money	x	x			2
	Contractor's general lack of commitment to adopt efficiency improvement tools	x	x			1
	Inspections are seen as a leadership strength of the construction manager		x			1
	Organisational policies		x			1
	Lack of interest from key project stakeholders	x	x			2
	Capacity issues		x			1
Environment (External)	Volatile site environment				x	1
	Accessibility to drone technology	x	x			1
	Determination of ground control station on complex site				x	1
	Flight in Accordance with Regulations	x		x		2

Table 5.1 above groups the challenges in accordance with the framework employed in this study. There are 8 challenges that fall under the technological aspect, 9 that fall under the organisational aspect, and 4 that fall under the environment aspect. The table presents these challenges supported by relevant sources from the previous chapters. Table 5.2 below extends this to a challenge matrix and organsise observed and experienced challenges outlined in chapter four in terms of their severity.

Table 5.2: Challenge matrix for observed and experience challenges (from the study)

	Nature	**Severity**				
		Insignificant	Minor	Moderate	Major	Severe
Occurrence		Impact on inspection process is negligible.	Impact on inspection process can be rectified immediately.	Impact may cause delay, but remedial measures are available.	Considerate remedial action not possible on site required	Extensive measures are required to remedy the challenge.
Known – unavoidable	Always occurs during time of drone use. There is a very strong chance of this challenge occurring. History shows that it is something that occurs frequently.		R	P		M, W
Expected – Avoidable	Expected to occur occasionally during time of drone deployment. Literature shows that this challenge occurs unacceptably too often.		N	L, Q		V
Predicted	More likely to occur than not occur during drone deployment. this challenge has occurred on several occasions.			O	U	
Unexpected	Not expected to occur during drone deployment. Literature shows that challenge occurs only on unusual circumstances.		Y	S		
Almost unprecedented	Not expected to ever occur during drone deployment. There is very little or no evidence from literature of this challenge ever occurring.				X	T

The nature and occurrence of observed and experienced challenges are presented above in table 5.2. the letters represent each challenge as explained below:

Experienced challenges:

Connectivity issues (Q); Battery life and inspection area (R); Poor data quality (S); Volatile site environment (T); Ground control points & terrain (U); Processing time and rendering (V); Software platform compatibility (W); Rapidity in data collection (X); Determination of ground control station on complex site (Y);

Observed challenges:

Data Acquisition Challenges (L); Data Processing & Analytics (M); Ground Control Station (GCS) Disturbances (N); Flight in Accordance with Regulations (O); Disturbance to site activities (P).

5.4. Research question three

How can identified challenges impeding optimal utilisation of drones during the execution stage of construction projects be addressed?

The literature reviewed highlighted that comprehensive strategies are needed to overcome the challenges that are preventing the widespread use of drone technology in the construction industry. The document analysis revealed that the strategies should cover areas such as regulation, collaboration, education, and strategic alignment.

Participants emphasised the need for flexibility in regulatory requirements and a risk-based approach to determine licensing processes. It was noted that by establishing a regulatory framework that accommodates the unique characteristics of drone operations, authorities can promote innovation and entrepreneurship in the drone industry while ensuring safety and compliance.

Collaboration and cooperation among industry players, regulatory authorities, and stakeholders also play a crucial role in overcoming adoption challenges. The document analysis also revealed the establishment of collaborative platforms and committees to facilitate communication, coordination, and knowledge sharing within drone ecosystems. However, participants noted that challenges may arise in public projects where drone programs are perceived as policing mechanisms rather than value-adding tools. Innately, effective stakeholder engagement strategies are needed to address such perceptions and foster a culture of collaboration and innovation.

Demonstrating the practical benefits and return on investment (ROI) of drone technology through proof-of-concept initiatives is another effective strategy that was outlined by participants. Pilot projects and trials showcase how drones can improve project outcomes (Falorca and Lanziha, 2020), enhance productivity, and drive cost savings. Participants indicated that aligning drone initiatives with broader project objectives could demonstrate their strategic relevance and value, garnering support from decision-makers and stakeholders.

Furthermore, securing buy-in from top management is essential for the successful integration of drone programs into organisational processes. Clear sponsorship and support from executive leadership ensure sustained investment and commitment to drone technology initiatives. Conversely, shifting priorities and changes in leadership can hinder adoption efforts, highlighting the importance of maintaining consistent support from top management.

On the other hand, addressing the lack of training institutions and suboptimal training capacity is critical for empowering construction professionals to leverage drone technology effectively. The choice between a top-down or bottom-up approach to technology adoption depends on the organisational context. While private sector actors may favour a top-down approach driven by executive management, public sector actors may advocate for a bottom-up approach driven by operational stakeholders. Essentially, aligning drone technology initiatives with operational needs and priorities ensures relevance and effectiveness in addressing adoption challenges.

Furthermore, exposing the value proposition of drone technology for construction industry professionals was outlined as crucial for driving adoption. Highlighting tangible benefits, such as enhanced efficiency, safety, and cost-effectiveness, can increase awareness and acceptance of drone technology (Albeaino *et al.*, 2021). Demonstrating how drones can revolutionize various aspects of construction projects, from visual interpretation of works on-site to improved project management, enhances their perceived value and relevance (Mahajan, 2021; Sawant *et al.,* 2022). Conversely, encouraging the expansion of drone service provision, including drone manufacturing, is essential for reducing costs associated with technology adoption.

Streamlined Regulatory Processes:

Participants highlighted the need for streamlined regulatory processes to facilitate the adoption of drone technology. This involves adopting a risk-based approach to determine regulatory requirements, simplifying licensing processes, and reducing bureaucratic barriers to entry. By creating a conducive regulatory environment, innovation and entrepreneurship in the drone industry can be promoted, ultimately fostering widespread adoption across various sectors (Yıldız, Kıvrak and Arslan, 2021).

Collaboration, Cooperation & Co-creation:

Collaboration among major industry players, regulatory authorities, and stakeholders was emphasised by participants as essential for advancing unmanned aviation and addressing challenges related to drone technology adoption. Establishing collaborative platforms and committees facilitates communication, coordination, and cooperation, driving dialogue and innovation within drone ecosystems (Sanson, 2019).

Proof of Concept:

Participants revealed that demonstrating successful use cases and contextually relevant scenarios of drone technology can mitigate implementation challenges and garner support for its adoption. Uptake of drone technology by big construction companies could showcase the practical benefits and return on investment (ROI) of drone technology to the rest of the construction industry (Ramos-Hurtado *et al.,* 2022; Freimuth and Koning, 2018).

Top Management Buy-in:

Securing buy-in from top management is crucial for the integration of drone programs into core services within organisations (Malomane *et al.,* 2022). Clear sponsorship and support from top management would ensure sustained investment and commitment to drone technology initiatives, overcoming challenges associated with shifting priorities and changes in leadership.

Training & Education:

Addressing the lack of training institutions and suboptimal training capacity requires the development of a national training footprint and comprehensive curriculum for drone training programs. Investing in education and upskilling initiatives could empower construction professionals to leverage drone technology effectively, overcoming challenges and maximising its potential for improved efficiency and productivity (Fan and Saadeghvaziri, 2019).

Top-Down/Bottom-Up Approach:

Participants emphasised the importance of adopting either a top-down or bottom-up approach, depending on the organisational context. While private sector actors favour a top-down approach driven by executive management, public sector actors advocated for a bottom-up approach driven by operational stakeholders. Aligning drone technology initiatives with operational needs and priorities ensures relevance and effectiveness in addressing challenges (Sibanda *et al.*, 2021).

Value Proposition:

Highlighting the value proposition of drone technology for construction industry professionals underscores its potential to revolutionise various aspects of construction projects, enhancing efficiency, safety, and cost-effectiveness. Demonstrating tangible benefits, such as visual interpretation of works on-site and improved project management, enhances the perceived value of drone technology, driving its adoption (Grosso *et al.*, 2020).

Drone Industry Niche:

Drone industry participants expressed that encouraging the expansion of drone service provision, including drone manufacturing, can help reduce costs associated with technology adoption. By fostering the growth and development of drone solutions, South Africa can leverage its expertise to produce world-class products and solutions, creating an environment conducive to innovation and economic growth.

Overall, these approaches encompass technological, organisational, and external factors aimed at overcoming challenges and fostering the optimal utilisation of drone technology in the construction industry.

5.4.1. Summary of suggestions to address impeding optimal utilisation of drones

The successful integration of drone technology in the construction industry hinges on several critical factors. Firstly, a flexible, risk-based regulatory framework is essential to accommodate drone operations, promoting innovation while ensuring safety and compliance. Strong collaboration among industry players, regulatory authorities, and stakeholders is also critical. Establishing platforms for communication and knowledge sharing can be a mitigative mechanism, particularly in public projects where drones may be misperceived as policing mechanisms. Demonstrating practical benefits through pilot projects is another effective strategy, showcasing the return on investment of drone technology and aligning initiatives with broader project objectives to garner stakeholder support. Additionally, securing buy-in from executive leadership is crucial for integrating drone programs into organisational processes, ensuring sustained investment and commitment.

Furthermore, addressing the lack of training institutions by developing comprehensive training programs can empower construction professionals to leverage drone technology effectively. The choice between a top-down or bottom-up approach to adoption should reflect the organisational context to ensure initiatives are relevant to operational needs. Lastly, emphasising the tangible benefits of drones such as improved efficiency, safety, and cost-effectiveness can enhance acceptance and drive adoption within the industry.

5.5. Chapter summary

This chapter provided a discussion of the findings that were presented in the previous chapters. The discussion encompassed the findings on drone industry evolution and the challenges to drone technology deployment for drone-aided inspections during construction execution in South Africa. Key discussions from this chapter entail the lack of capital and resource allocation, concerns about transparency and contractual accountability, and the need for clear evidence of return on investment. Technical complexity, disruption to site activities, lack of interest from key stakeholders, capacity issues, and connectivity issues were also discussed as hinderances to the adoption of drone-based approaches.

The discussion explained that the implementation of drones in South African construction projects faces technological, organisational, and environmental challenges. Additionally, the discussions encompassed strategies to overcome challenges impeding the optimal use of drones in construction projects. By juxtaposing the findings of this study with reviewed extant literature, the discussion aligned the results of the research with the existing body of knowledge. Thus, having discussed the findings of this study, it is essential to provide conclusive remarks and recommendations based on the discovered findings. Therefore, the next chapter outlines the conclusion to the research.

CHAPTER 6: CONCLUSIONS AND CONTRIBUTION

6.1. Introduction

This research assessed the challenges hindering the deployment of drones on construction sites for drone-aided inspections by key role players during construction project execution. Essential background information, articulating the primary problem statement, and delineating the research aim, main question, objectives, and scope were provided in chapter one. Chapter two delved into an extensive literature review, exploring the evolution of construction site inspections, the challenges therein, and the potential of drone technology to address these challenges, concluding in the development of a conceptual framework. The research methodology employed, describing the approach to data collection and analysis to effectively address the research question, was detailed in chapter three. In Chapter four, the findings from document analysis, case studies, and interviews with industry professionals were presented and analysed to meet the research objectives. Subsequently, Chapter five engaged in a comprehensive discussion of the empirical results, juxtaposed with existing literature and framed within the DOI-TOE framework, offering valuable insights into the research topic.

The main purpose of this chapter is to draw conclusion from the findings to highlight their significance for the construction industry and academia, and provide actionable recommendations for future research endeavours, thus culminating the dissertation with a meaningful contribution to the field of construction project management. This chapter provides a concise overview of the study's objectives, empirical and theoretical contributions, and the implications derived from the findings. Nevertheless, the limitations of the study are also presented.

6.2. Revisiting the aims and objectives

The research aim was to assess the challenges hindering the deployment of drones on construction sites for drone-aided inspections by key role players during construction project execution, to improve understanding of these challenges with the intention to provide recommendations to mitigate them in order to optimise success in the utilisation of drone technology in construction projects.

The aim was achieved by accomplishing the three objectives. First, the ascertainment of the state and potential of drone technology adoption in South Africa's construction industry. Second, empirical evidence from case studies illustrated the practical impact of these challenges during actual drone deployments, enriching the assessment. Finally, proposing solutions such as streamlining regulatory processes and enhancing stakeholder collaboration offered pathways to overcome these barriers. Together, these objectives comprehensively address the aim, facilitating a better understanding of how to optimise drone technology implementation in construction.

6.3. Assessing the research premise

In addressing the first objective, the findings revealed the evolving landscape of drone technology in South Africa, emphasising both the potential for growth and the current limitations due to regulatory hurdles and market readiness. This aligned with the premise posited by signifying that while there is a growing market for drones, significant barriers still exist. The second objective delved into the challenges directly impacting drone inspections in construction. Factors such as low-quality data transmission, lack of commitment from contractors, and fears surrounding transparency were revealed, which directly supported the notion that understanding these challenges is crucial for improvement.

The third objective focused on solutions, emphasising the need for streamlined regulations, collaboration among stakeholders, and successful proof-of-concept initiatives. This reflected the premise's assertion that identifying and addressing these challenges can lead to better integration of drone technology in construction. Thus, the research premise was effectively supported by demonstrating both the challenges faced and the strategies that can be employed to enhance drone utilisation in the construction industry.

6.4. Review of the research methodology

This study is based on the interpretivism paradigm and is guided by the exploratory nature of the research. The research employed an inductive approach to assess the challenges associated with drone-aided inspections. The exploration of this concept involved utilising a qualitative approach that included document analysis and a case study strategy. This approach required analysing relevant documents and conducting semi-structured interviews with professionals in construction project management and drone service providers. The techniques used in this study provided comprehensive data that established an in-depth understanding of the challenges faced in implementing drone technology in construction. The data underwent analysis using content analysis and thematic analysis techniques. Thus, through detailed analysis, the research questions were answered. Therefore, the conclusion presented in this chapter is based on the results from the literature review and the empirical findings.

6.5. Research scope

This study examined various aspects of construction inspections and focused specifically on quality control inspections, introducing the use of drone technology as a more efficient alternative to current inspection methods in the construction industry. This research is centred around key construction project management role players involved in construction projects in South Africa and drone operators who offer drone technology services for construction-related applications. A conceptual framework was developed using the DIT and the TOE framework. The empirical component of this study is narrowed to gathering insights from construction project managers and drone service providers with experience in the public and private sectors in SA within Gauteng province. Prior, an analysis was conducted on documents related to the drone market, policy, and drone service providers. The relevant stage of the construction delivery is the construction documentation and management stage, as outlined by the SACPCMP (SACPCMP, 2021). The successful management and administration of construction contracts and processes is the ultimate goal of this stage. Nonetheless, this research is focused on the improvement of drone technology uptake within the construction industry in South Africa.

6.6. Conclusions on the research questions and objectives

RQ1: What is the diffusion of commercial drones for construction related applications within the South African construction industry?

Objective 1: To ascertain the diffusion of commercial drones for construction related applications within the South African construction industry.

The drone industry in South Africa is evolving rapidly, influenced by regulatory adaptation and increasing integration into various sectors. The regulatory landscape is undergoing amendments to improve the drone industry, emphasising the importance of legislative and regulatory frameworks in shaping industry growth. The findings address the diffusion of commercial drones for construction-related applications in South Africa by highlighting several key aspects: the evolution of commercial drones in South Africa, market availability of commercial drones in South Africa, and the current state of South Africa's drone industry. The evolution of commercial drones in South Africa is driven by advancements in technology and growing trends in drone technology innovation ecosystems. The drone economy transformation has led to a robust drone economy, encompassing various activities such as service provision, manufacturing, and infrastructure development. Regulatory development advocacy aims to develop policies and regulations that support the growth of the drone industry.

The market availability of commercial drones for construction in South Africa is growing, with a range of models, accessories, and services adaptable for construction-related applications. However, there is a need for regulatory reform and efficiency improvements to improve the industry's competitiveness and attract increased adoption, more so within the construction industry. Strategies to facilitate large-scale adoption of drones, futureproof drone regulations, and address security and privacy concerns are being considered. This includes aligning training programs with aviation qualifications, increasing training capacity, knowledge transfer, and job creation initiatives. The data suggests that South Africa has the potential to become a significant player in the global drone market but must overcome regulatory and investment constraints.

This achieves the objective by highlighting key aspects of the diffusion of commercial drones in South Africa's construction industry. The evolving landscape that supports integration emphasises the growing market availability of various drone models and services tailored for construction, and notes advancements in technology driving adoption. Collectively, these elements illustrate the current state and future potential of drone technology within the construction sector.

RQ2: *What is the nature and occurrence of challenges to drone technology deployment for drone-aided inspections during construction execution stage of projects in South Africa?*

Objective 2: To determine the nature and occurrence of challenges to drone technology deployment for drone-aided inspections during construction execution stage of projects in South Africa.

The study aimed to identify and outline the challenges impacting the implementation of drone technology for construction site inspections within construction projects. The most perceived challenges were capital and resource allocation from owners, transparency and contractual accountability fears, value for money, contractor's general lack of commitment to adopt efficiency improvement tools, and organisational policies. The implementation of a drone-based approach in construction projects faces several major deterrents, including lack of interest from key stakeholders, accessibility to drone technology, and capacity issues. Key stakeholders play crucial roles in decision-making and project execution, and their disinterest may result in reluctance to allocate resources towards implementing drone solutions.

Observation findings revealed challenges during drone deployment for drone-aided construction site inspections. Challenges include low-quality live visual data, visual inconsistencies at certain locations, poor signal during live broadcast, and disturbances at ground control stations (GCS). Adhering to regulatory requirements is crucial for safe and compliant drone operations but maintaining constant visual contact with the drone throughout the inspection process can be challenging due to complex site environments. Disturbances to site activities during the drone deployment can also cause distractions for site personnel.

The drone deployment process on three construction sites faced several challenges, including connectivity issues affecting data transmission quality, battery limitations causing operational delays, and volatile site conditions disrupting operations. Poor connectivity and lighting variations compromise data quality, hindering effective analysis. Participants reported that they experienced interruptions and delays in data transmission, pixelation, blurriness, and buffering during the broadcast. Overall, challenges encompassed various aspects, including technical, regulatory, operational, and organisational factors, emphasising the nature of challenges to the implementation of drone technology in construction projects.

By detailing these challenges, the study provides a comprehensive understanding of the nature and occurrence of obstacles in adopting drone technology in South Africa's construction projects, highlighting areas for potential improvement and intervention. Thus, effectively meeting the objective by identifying and outlining challenges that directly impact the deployment of drone technology for inspections and illustrating the operational difficulties faced during the construction execution stage.

RQ3: How can identified challenges impeding optimal utilisation of drones during the execution stage of construction projects be addressed?

Objective 3: To suggest ways of addressing identified challenges impeding optimal utilisation of drones during the execution stage of construction projects.

The third objective of this research was to address challenges impeding the adoption of drone technology in the construction industry. The literature review identified challenges that hinder the optimal utilisation of drone technology for construction project-related applications. A case study method was used to collect empirical evidence, identifying the nature and occurrence of these challenges during drone deployment on a construction site in objective two. The findings from the interviews under objective 3 reveal that the importance of streamlining regulatory processes to facilitate drone technology adoption, advocating for flexible requirements and simplified licensing procedures. Collaboration among industry stakeholders and regulatory authorities was deemed essential for addressing adoption challenges, fostering communication, and driving innovation within drone ecosystems.

Demonstrating successful use cases through proof of concept emerged as a key strategy to mitigate implementation challenges and garner support for drone technology adoption, aligning initiatives with broader project objectives.

Additionally, stakeholders emphasised the need to align drone technology initiatives with organisational needs and priorities, adopting either a top-down or bottom-up approach depending on the context. Overcoming challenges in the implementation of drone technology in construction requires a multifaceted approach by both construction and drone industry professionals. Streamlining regulatory processes, demonstrating proof of concept through successful use cases, investing in training and education initiatives, and involving operational personnel in decision-making processes can help realise the full potential of drone technology.

The objective is achieved by outlining specific strategies to address challenges in utilising drone technology during construction projects.

6.7. Limitations of the study

The limitations to this study are presented below.

6.7.1. Methodical

The methodological strategy consisted mainly of gathering qualitative data in small sample sizes. Three cases were examined to understand the nature and occurrence of the challenges, and the opinions of 11 participants were collected to address these challenges.

To enhance the study, it would have been beneficial to involve a larger number of participants in the interview process, thereby obtaining a wider range of subjective perspectives. Moreover, consider expanding the study to incorporate a mixed method approach that encompasses quantitative data collection as well. This is due to the inability to measure the acquired responses and the lack of objective verification of these results by the researcher.

Furthermore, the study focused on cases and participants from the Gauteng province. Nevertheless, Gauteng is widely regarded as the nation's economic centre, suggesting that these findings could accurately represent the construction industry as a whole.

6.7.2. Physical constrains and scope limitations

This research only focused on stage 5 of construction project delivery. Therefore, the other stages where drone technology could also be used were not considered.

Lack of variety in the types of drones used: there was only one type of drone used across all the three cases due to the difficulty in finding a drone service provider who could assist the researcher.

Furthermore. the researcher could not get access to a drone service provider who could operate in a private construction project. Hence, all the three cases in this study are of public sector contracts. In future, a balance in the cases between public and private contracts would provide more robust findings that is a reflection of both the public and private sector.

6.8. Recommendations

Based on the findings of the study, the following recommendations are proposed.

6.8.1. Recommendations for industry

<u>Streamline regulatory Processes:</u>
Government and industry drone industry stakeholders should collaborate to develop clear and streamlined regulations for drone usage in construction projects.

<u>Invest in training and education:</u>
Construction companies should invest in training programs to equip personnel with the skills and knowledge required to operate drones effectively, leveraging their capabilities.

<u>Foster industry collaboration:</u>

Establish industry-wide partnerships and knowledge-sharing initiatives to accelerate the adoption of drone technology within the industry, to address common construction project process problems.

6.8.2. Recommendations for academia

There needs to be a realisation that drone technology will impact the construction industry in a similar manner to that of technologies such as BIM. Hence it is recommended that drone technology is incorporated in construction related studies, exploring how drones as tools can reshape certain practices.

Given the multidisciplinary nature of drone technology applications in construction, academia should promote interdisciplinary collaboration between researchers from fields such as engineering, construction management, urban planning, and aviation. Collaborative research efforts can lead to holistic insights and innovative solutions to overcome challenges related to drone deployment in construction project management.

Furthermore, encourage applied research projects that focus on translating theoretical knowledge into practical solutions for real-world challenges faced by the construction industry. Working with industry players on drone research initiatives can help validate research findings, test innovative technologies, and accelerate the adoption of drone technology in construction project delivery processes.

6.8.3. Suggested areas for future research

Although this research has successfully achieved its aim and made a valuable contribution to knowledge, there is still potential for further exploration of drone technology implantations in construction projects. Hence, the subsequent suggestions are advised for future research:

Research exploring the integration of drone-generated data with BIM platforms to enhance construction project planning, design, and management: Studies should examine the interoperability between drones and BIM software, data exchange protocols, and the use of drones for as-built verification and quality assurance purposes.

Future research should focus on conducting comprehensive cost-benefit analyses and ROI assessments of drone technology adoption in construction project management. This includes evaluating the financial implications, productivity gains, risk mitigation, and long-term value proposition associated with integrating drones into construction workflows.

Research investigating the human factors involved in the effective use of drones for construction site inspections: This should include studying the impact of training programs, user interfaces, and decision-making processes on drone operators and construction personnel.

6.9. Research contributions

6.9.1. Contribution to body of knowledge

Within academic discourse, the study advanced the understanding of drone technology applications in construction project management, particularly focusing on its potential for enhancing and streamlining inspections of construction works. By presenting the nature and impact of challenges to drone technology deployment, the research set a foundation for future studies on real-time drone-based inspections during construction execution in South Africa.

Moreover, the research provided an exploratory platform for understanding the challenges hindering the optimal utilisation of drones for construction site inspections. This paradigm shift encourage discourse on leveraging drone technology as a tool for enhancing processes during the construction execution, thereby stimulating future discussions on the potential utility of drones in construction.

6.9.2. Contribution to practice

By highlighting the prevalence of the challenges within the local construction landscape, the research creates awareness among key industry professionals about how these challenges impede the utilisation of drones for efficient inspections of construction projects.

Furthermore, by analysing the impact of these challenges, construction industry stakeholders could derive strategic approaches to address them, ultimately fostering the wider adoption of drone technology.

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APPENDICES

Appendix A: Ethical clearance certificate

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Research Office

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)
R14/49 Khorombi

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER: H23/06/17**
PROJECT TITLE	Exploring the challenges to drone-aided inspections in construction site management
INVESTIGATOR(S)	Mr S Khorombi
SCHOOL/DEPARTMENT	Construction Economics & Management/
DATE CONSIDERED	23 June 2023
DECISION OF THE COMMITTEE	Approved Risk Level: Minimal
EXPIRY DATE	09 October 2026

DATE 10 October 2023 **CHAIRPERSON** ________________
(Professor J Watermeyer)

cc: Supervisor : Dr R Terblanche

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **A SIGNED COPY** returned to the Secretary electronically. Unreported changes to the application may invalidate the clearance given by the HREC (Non-Medical)

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure be contemplated from the research procedure as approved I/we undertake to submit an amendment of the protocol to the Committee. **I/we agree to completion of a regular progress report. For Minimal and Low Risk studies, this is due annually on 31 December. For Medium and High Risk studies, this is due twice annually on 30 June and 31 December.**

________________ 10 / 10 / 2023
Signature **Date**

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES

Appendix B: Participant information sheet – contextual inquiry

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

SCHOOL OF CONSTRUCTION ECONOMICS AND MANAGEMENT

Good day

My name is Shadrack Khorombi, I am a Masters student in Building (Construction Project Management) within the School of Construction Economics and Management at the University of the Witwatersrand, Johannesburg. My supervisor is Dr. Rolien Terblanche. I am conducting a research study about the application of drone technology in construction project management. The study title is "Exploring the challenges to drone-aided inspections in construction site management".

I am inviting you to take part in a contextual inquiry which will comprise three stages on a construction site. Your involvement in the first stage will include you answering some interview questions. If you decide to take part, your participation in this interview session will last about 30 minutes. The second stage will be an observation by the researcher of a drone deployment process on the construction site. Here, I will also observe how you function and interact with the drone while your task is being aided by drone technology. This session will last about 1 hour. For the third stage, you will be required to participate in a single interview session. This interview session will also last for 30 minutes. All three activities will take place on the construction site where you work, during work hours and will be a once off activity.

With your permission, I would like to audio record the interview sessions. This data will be stored in my personal computer and personal google drive for 10 years and deleted after 10 years. Only myself as the principal researcher will have access to the data. Also, I will be taking pictures of the drone during the deployment process and I will ask you to consent to being photographed in case you are in close proximity with the drone as I am taking a picture.

During the research activity, I will need to ask for some personal information about you, including your age, gender and role.

The interviews will be confidential and I will not tell anyone what you, as the participant tells me. When I share the results of the research study, I will not include your name or anything else that could identify you. Given the nature of the study, your anonymity cannot be guaranteed during the data collection process as I will know your identity. If you withdraw participation at any time during any of the three stages of the contextual inquiry, I will also destroy the data you have shared to that point.

If you decide to take part in the research study, it should be because you want to volunteer. You do not have to take part. You can stop being in the study at any time. You do not have to answer any questions if you do not want to. You will not get any direct benefits if you choose to join the research study. You will not lose any services, benefits or rights you would normally have if you decide not to join. Taking part in the research study will not cost you anything. You will not be paid for being in this research study.

The risks for this research study are no more than what happens in everyday life. A risk related to the operation of a drone on the construction site during drone deployment is minimal. The CAA states that all commercial drones must be operated by a licensed professional. Therefore, the experienced drone pilot will perform all necessary procedures prior to deployment to ensure that no accidents occur during drone operation. All participants involved will remain at a safe distance recommended by the drone pilot at all times. As such, there are no risks involved that would bring harm or cause stress to you.

This research study will be written up as a research report. The report will be available on the university library website. If you would like to receive a summary of this report, I will be happy to send it to you.

If you have any questions during or afterwards about this research study, feel free to contact me or my supervisor on the details listed below. If you have any concerns or complaints about the ethical procedures of this research study, you are welcome to contact the University Human Research Ethics Committee (Non-Medical), telephone +27(0) 11 717 1408, email hrecnon-medical@wits.ac.za.

Yours sincerely,
Shadrack Khorombi

Researcher:
Shadrack Khorombi, 832223@students.wits.ac.za, 0763547444

Supervisor:
Rolien Terblanche, Rolien.terblanche@wits.ac.za, 011 717 7669

Appendix C: Consent form – contextual inquiry

Faculty of Engineering and the Built Environment
School of Construction Economics & Management
University of the Witwatersrand, Johannesburg
Private Bag X3
WITS
2050

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Title of project: Exploring the challenges to drone-aided inspections in construction site management.
Researcher: Shadrack Khorombi

I ………………………………………………………………………… agree to participate in this research project. I agree to the following.

(Please tick the relevant options below)

The research study was explained to me. I understand what this study is about.	Yes	No
I understand that my participation is voluntary and that I am free to withdraw at any time, without giving reason.		
I agree that potential risks and harms were explained to me.		
I agree that my participation will remain confidential (the researcher will not disclose to anyone else what I say during the interview).		
I understand that anonymity cannot be guaranteed given the nature of the research.		
I understand that data is stored in a secure location where no unauthorized access is available.		
If I have any queries, I have been informed of who I need to contact.		
I understand that the data collected from my participation will only be use by the principal researcher, and will not be shared with anyone else.		
I agree that the interview session may be audio recorded, and for the audio recording to be used for data analysis purposes.		
I understand that photos of the drone will be taken, and agree that the researcher may take photos of the drone with me in the picture frame.		
I agree that direct quotations from my interview may be used by the researcher in their research report and no identifying information will be used in the transcript.		

Signed: Date:

…………………………………………… ……………………………………………

Appendix D: Participant information sheet – interviews

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

SCHOOL OF CONSTRUCTION ECONOMICS AND MANAGEMENT

Good day

My name is Shadrack Khorombi, I am a Masters student in Building (Construction Project Management) within the School of Construction Economics and Management at the University of the Witwatersrand, Johannesburg. My supervisor is Dr. Rolien Terblanche. I am conducting a research study about the application of drone technology in construction project management. The study title is "Exploring the challenges to drone-aided inspections in construction site management".

I am inviting you to take part in a single interview session where you will answer some questions. If you decide to take part, your participation in this research study will last about 45 minutes. The interview will take place either at your workplace or at a convenient place of your choosing, during work hours.

With your permission, I would like to audio record the interview session. This data will be stored in my personal computer and personal google drive for 10 years and deleted after 10 years. Only myself as the principal researcher will have access to the data.

During the research activity, I will need to ask for some personal information about you, including your age, gender and role.

The interview will be confidential and I will not tell anyone what you, as the participant tells me. When I share the results of the research study, I will not include your name or anything else that could identify you. Given the nature of the study, your anonymity cannot be guaranteed during the data collection process as I will know your identity. If you withdraw participation at any time during the interview session I will also destroy the data you have shared to that point.

If you decide to take part in the research study, it should be because you want to volunteer. You do not have to take part. You can stop being in the study at any time. You do not have to answer any questions if you do not want to. You will not get any direct benefits if you choose to join the research study. You will not lose any services, benefits or rights you would normally have if you decide not to join. Taking part in the research study will not cost you anything. You will not be paid for being in this research study.

The risks for this research study are no more than what happens in everyday life. As such, there are no risks involved that would bring harm or cause stress to you.

This research study will be written up as a research report. The report will be available on the university library website. If you would like to receive a summary of this report, I will be happy to send it to you.

If you have any questions during or afterwards about this research study, feel free to contact me or my supervisor on the details listed below. If you have any concerns or complaints about the ethical procedures of this research study, you are welcome to contact the University Human Research Ethics Committee (Non-Medical), telephone +27(0) 11 717 1408, email hrecnon-medical@wits.ac.za.

Yours sincerely,
Shadrack Khorombi

Researcher:
Shadrack Khorombi, 832223@students.wits.ac.za, 0763547444

Supervisor:
Rolien Terblanche, Rolien.terblanche@wits.ac.za, 011 717 7669

Appendix E: Consent form – interviews

Faculty of Engineering and the Built Environment
School of Construction Economics & Management
University of the Witwatersrand, Johannesburg
Private Bag X3
WITS
2050

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Title of project: Exploring the challenges to drone-aided inspections in construction site management.
Researcher: Shadrack Khorombi

I ……………………………………………………………………………… agree to participate in this research project. I agree to the following.

(Please tick the relevant options below)

The research study was explained to me. I understand what this study is about.	Yes	No
I understand that my participation is voluntary and that I am free to withdraw at any time, without giving reason.		
I agree that potential risks and harms were explained to me.		
I agree that my participation will remain confidential (the researcher will not disclose to anyone else what I say during the interview).		
I understand that anonymity cannot be guaranteed given the nature of the research.		
I understand that data is stored in a secure location where no unauthorized access is available.		
If I have any queries, I have been informed of who I need to contact.		
I understand that the data collected from my participation will only be use by the principal researcher, and will not be shared with anyone else.		
I agree that the interview session may be audio recorded, and for the audio recording to be used for data analysis purposes.		
I agree that direct quotations from my interview may be used by the researcher in their research report and no identifying information will be used in the transcript.		

Signed: Date:

………………………………………………… …………………………………………………

Appendix F: Data collection instruments

Fieldwork Data Collection Procedure		Case A	Case B	Case C
Project Description	Type of construction	Residential Building	Commercial Retail Center	Highway Infrastructure
	Location:			
	Project Duration:			
	Current Timeline:			
	Project Type:			
Main Objective:	To determine the challenges in deploying drones for drone-aided construction site inspections.			
Approach	Drone Type to be Used			
	Phase 1: Pre-inspection Interviews	Interviews on perceived (subjective) challenges		
	Phase 2: Inspection Event	Observation of challenges based on predetermined checklist		
	Phase 3: Post-Inspection Interviews	Interviews on experienced (objective) challenges		
Drone-Aided Inspection Event Observation Sheet	Brief description of inspection			
	Type of Inspection			
	Brief description of challenges & occurrence			
	Challenge causation			
	Direct Immediate effects			

	Challenge Severity			
	Challenge frequency			
Critical Analysis	Direct immediate reaction to the challenge			

Interview Session 1 Questions

Phase 1 – Interview Session One.

Interview with key role players identified in objective 1, on their perceptions of challenges they might face in the deployment of drone technology for drone-aided construction inspections.

		Interview Session 1 Questions
Introductory Questions	1	What is your role in the process of carrying out construction site inspections?
	2	What are your responsibilities to ensure quality inspections of construction site works during project execution?
Main interview Questions	3	What challenges do you think you might encounter in attempting to deploy a drone on your construction site for drone-aided inspections?
	4	What challenges do you think you might face during the deployment of a drone on your construction site for drone-aided inspections?
	5	Based on your role, what other challenges across the board do you think might hinder the implementation of a drone-based approach for inspections of construction works?

	6	How have these challenges deterred you from wanting to get a drone to aid construction inspections?

Observation Checklist

Phase 2 – Observation Checklist

Below is the observation checklist that the researcher will use as guides in recording observations during fieldwork.

1. Observe challenges faced by the inspection team when their performance is being aided by drone technology.
2. Observe any challenges faced when visualizing video surveillance from drone operator.
3. Observe challenges in real-time connectivity of key stakeholders during the inspection.
4. Observe any challenges faced by the drone.

Interview Session 2 Questions

Participants in this phase are those that were involved in the deployment of drone technology on their construction site for drone-based inspections of construction works.

Interview Question Type	Q	Interview Session 2 Questions
Introductory Question	1	What was your role in the process of carrying out construction site inspections?
	2	What were your responsibilities to ensure quality inspections of construction site works during project execution?
Main Interview Questions	3	What challenges did encounter in the attempt to deploy a drone on your construction site for drone-aided inspections?

	4	What challenges did you face during the deployment of a drone on your construction site for drone-aided inspections?
	5	Based on your experience with the technology, what other challenges across the board do you think hindered the implementation of a drone-based approach for the inspection of construction works?
	6	How have these challenges demotivated you from moving toward drone technology application to aid construction inspections?
	7	Which of these challenges were the biggest in the efforts to adopt a drone-based inspection approach?
Suggestive Remarks Question	8	In your professional view, how can these challenges be addressed/dealt with?

Biographical Information Form

Age			
Gender	**MALE**	**FEMALE**	**OTHER**
Occupation/Job title			
Work Experience (Years)			
Work Location	**Site Based**	**Office Based**	
Previous Experience with a Drone	**YES**	**NO**	
If yes, for what use/applications?			