3D PROPERTY OBJECTS IN SOUTH AFRICAN LOCAL GOVERNMENT:

THE NECESSITY OF REPRESENTING AND MANAGING THE THIRD DIMENSION IN THE CITY OF CAPE TOWN PROPERTY MANAGEMENT SYSTEM

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ABSTRACT

The objective of this research was to analyse whether there is a need for a form of 3D Land Administration System (LAS) in South Africa (SA) based on the land administration functions of land tenure, land use, land development and land value. The investigation can be divided into two key focus areas that align with subsystems of the LAS: (i) the Land Tenure System (LTS) that is responsible for land tenure; and (ii) the Property Management System (PMS) that is responsible for land use, development and value. These two key areas fall within the SA LAS and make use of the cadastre as a foundation. Humby (2014) focussed on the first subsystem and found that there may be a significant need within the LTS for a 3D cadastral record or a 3D legal property object (LPO). The second subsystem is the focus of this study.

To analyse the need for 3D in the PMS, the City of Cape Town (CCT) was adopted as a single case study, and modelled using systems thinking tools. The model focussed on the definition, use and management of property information, or the conceptual 3D property management object (PMO), to fulfil the land administration functions of land use, development and value within the CCT PMS. Established land administration theory, including the Land Management Paradigm, the good governance principles and RRR requirements, was used as a foundation against which the CCT PMS was analysed. This allowed for an increased understanding of the current CCT PMS's ability to achieve its land administration goals, policies and sustainable development.

Following this, the current use of 3D within the CCT PMS was presented and analysed, along with the potential resulting benefits, uses and challenges of introducing 3D into that system. Semi-structured in-depth interviews, documentation evidence and participant and direct observations were employed in this section of the research. Furthermore, international land administration and 3D experiences, as presented in the literature review, were incorporated in this analysis.

This study concludes that introducing a third dimension into the CCT PMS would have its challenges, but the uses and benefits that have been seen globally and that are recognised within the CCT, may outweigh those challenges. The research illustrates how a 3D Property Management Object would clarify the records and aid the land administration functions. Preferably, 3D would be introduced into the cadastre and LTS initially, and the PMS could then adopt that real RRRs LPO record as a foundation for the PMO records. However, the LTS has fallen behind in technology and it appears the CCT PMS will have to take the lead in introducing 3D into the SA LAS. It is recommended that a full cost-benefit analysis is conducted prior to any further research or development within the CCT.

ACKNOWLEDGEMENTS

I would like to thank my supervisors, Professor Jennifer Whittal and Dr Simon Hull, for being exceptionally patient and understanding throughout this journey. The same must be said for my husband, Jannik, and my family; who supported me without question throughout the long evenings and weekends of work. Thanks must be extended to those who very willingly gave up their time to participate in the interview process and impart their knowledge, thoughts and understanding of the CCT systems and the potential of a 3D city model. I learned so much through that experience. Finally, this research would not have been possible without the support of the City of Cape Town's Geospatial Unit, in particular Thomas Reiner, Geoff Dekker and Samantha Goodchild-Brown, whose passion for smart cities and 3D is inspiring.

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It should be noted that the views of the interviewed City of Cape Town officials and the research author that are presented here are not official City of Cape Town policy.

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2D	Two dimensions / two-dimensional
3D	Three dimensions / three-dimensional
BDM	Building Development Management (department)
BPM	Business Process Modelling
CCT	City of Cape Town
CGIS	Corporate GIS production geodatabase
DAMS	Digital Application Management System
DFD	Data flow diagram
DMS	CCT Development Management Scheme, Schedule 3 of the Municipal Planning By-law, 2015
GGP	Good Governance Principles
GIS	Geographic Information Systems
GRM	Government Revenue Management (System)
IS&T	Information Systems and Technology (department)
LAS	Land Administration System
LMP	Land Management Paradigm
LOD	Level of Detail
LPO	Legal Property Object
LTS	Land Tenure System
LUM	Land Use Management (department)
MMR	Mixed Methods Research
PBDM	Planning & Building Development Management (directorate)
PMO	Property Management Object
PMS	Property Management System
PSRM	SAP Public Services Records Management module
RRRs	Rights, Restrictions & Responsibilities
SA	Republic of South Africa / South African
SAP	Systems, Application & Processes
SAP LUM	SAP Land Use Management module
SDG	Sustainable Development Goal(s)
SDI	Spatial Data Infrastructure
SSM	Soft Systems Methodology

3D PROPERTY OBJECTS IN SOUTH AFRICAN LOCAL GOVERNMENT:

THE NECESSITY OF REPRESENTING AND MANAGING THE THIRD DIMENSION IN THE CITY OF CAPE TOWN LAND ADMINISTRATION SYSTEM.

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Chapter 1 INTRODUCTION

Section 1.1 The Need for a 3D Property Tool in Land Administration

South Africa (SA), like many developing countries, is facing a growing trend of urbanisation[1] causing an insatiable need for development. The repercussions of this are starting to show in cities like Cape Town and will intensify over the coming years. There is increased pressure to supply housing, adequate services and infrastructure to this steadily growing urban population. Simultaneously, it is necessary to maintain accurate records of what is happening on the ground to enable tenure security, property taxation, and effective land use planning and development.

Cities are highly complex systems (Dembski *et al.*, 2020) and the escalating demand for space is resulting in as yet unseen complexity in land rights and uses, creating overlapping and interlocking rights, restrictions and responsibilities (RRRs) volumes that are difficult to translate into two dimensions (2D)(Stoter, 2004; Zhang *et al.*, 2016). Additionally, it is challenging to extract the necessary information from the 2D records, risking confusion or mistranslation (Humby, 2014).

The Land Administration System (LAS) is at the foreground of the urbanisation crisis and, if adapted and used adequately, can result in a sustainable solution for SA. To achieve this, the LAS will have to cope with the increasing volume and complexity of property. Successful management of property is essential to ensure sustainable development, economic growth, tenure security, sufficient infrastructure and service delivery, fair property taxation, and adequate land use planning (Williamson *et al.*, 2010; Fisher & Whittal, 2020). This introduces the four primary functions of land administration, namely, (i) land tenure; (ii) land use; (iii) land development; and (iv) land value (encompassing valuation and taxation)(see 3.1.3)(Enemark, 2006a, 2005; Williamson *et al.*, 2010a; Karki, 2013; Enemark *et al.*, 2016; Rajabifard *et al.*, 2019).

The cadastre, a 2D record of real property RRRs, forms the foundation of these land administration functions within the LAS (Williamson *et al.*, 2010; Kitsakis *et al.*, 2018). It has been recognised internationally that introducing the third dimension (3D) into the cadastre, and consequently into the LAS, enables improved land management and tenure security (Williamson *et al.*, 2010a; Stoter, 2004; Enemark *et al.*, 2005; Shoshani *et al.*, 2005; Jones & Land, 2012; Ho *et al.*, 2013; van Oosterom *et al.*, 2020). Furthermore, the reality of property RRRs can be accurately and effectively captured, managed and used to achieve the goals of the Land Management Paradigm (LMP)(Williamson *et al.*, 2010). Humby (2014) showed that there is a need for clarity with respect to the third dimension of real (registrable) rights that affect tenure security. This study will investigate whether the

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[1] According to the UN DESA World Urbanization Prospects Report, the SA urban population will increase by a further 23.9% by 2050 (UN DESA, 2019).

remaining three land administration functions of land use, development and valuation, are currently successfully achieved in SA with respect to the third dimension. (The term 'third dimension' and other definitions pertinent to this research are defined in **Appendix A: Operating Definitions**.)

1.1.1 THE SOUTH AFRICAN LAND ADMINISTRATION SYSTEM

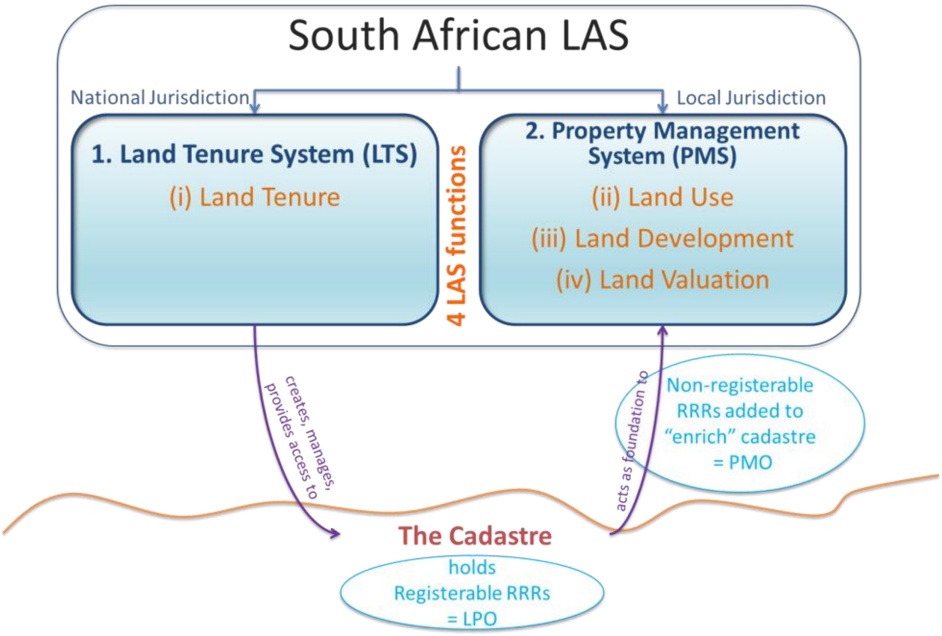

Figure 1-1: An Overview of the South African LAS and its sub-systems, the LTS and PMS, which function towards achieving the four land administration goals.

The SA LAS (see Figure 1-1) can be divided into two independent sub-systems that align with the land administration functions. The first subsystem, the Land Tenure System (LTS)(see 5.1.2i), is responsible for the primary function of the LAS, land tenure, including the creation, management and maintenance of real property RRRs within the cadastre and the deeds registry. This subsystem falls within national government jurisdiction and is governed by national legislation.

The remaining three land administration functions, namely, land use, development and value, fall within local government jurisdiction. These can be assigned to one subsystem per municipality, henceforth referred to as the Property Management System (PMS)(see Chapter 5). Each municipality is responsible for their own PMS and it is governed by national and municipal legislation. As this is a local government-specific PMS, this research will focus on the City of Cape Town's (CCT) PMS (see Section 1.6 for justification). These systems ground their land administration functions on the nationally-held 2D cadastre as a foundational layer. Furthermore, the cadastral foundation is appended according to each land administration purpose with non-registrable RRRs that stem from land policies as defined by Williamson *et al.* (2010) (see Figure 1-1).

1.1.2 THE LEGAL PROPERTY OBJECT AND THE LAND TENURE NEED

The SA cadastre is established on the notion that property[2] is a 2D entity that can be delineated by the boundaries of a surface parcel. However, the RRRs attached to that parcel imply a volume, creating a property object

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[2] Land and property are defined in Section 3.4.

(Humby, 2014; Fisher & Whittal, 2020) or a theoretical Legal Property Object (LPO)(Kalantari *et al.*, 2008). The record of the real RRRs attached to the surface parcel is held in the cadastre (see Figure 1-1).

The LPO is defined here to provide for differentiation between the traditional 2D erf and the 3D RRRs object that is implied by it. The erf is the physical 2D area on the earth's surface that denotes RRRs both horizontally and vertically (Humby, 2014). The LPO consists of these implied RRRs that form a volume that may or may not be bounded by the erf boundaries. A definition can be adopted from Oosterom *et al.* (2011): it is the multidimensional[3] spatial object against which one or more unique and homogeneous real RRRs are associated to the whole (object). The RRRs are homogeneous if the same combination of RRRs applies equally across the entirety of that object, and they are unique if "this is the largest object for which this is true" (van Oosterom *et al.*, 2011: 5). It must be emphasized that the LPO holds only registrable (real) RRRs in property, as defined in Fisher and Whittal (2020), and that the LPO does not necessarily relate to developed spaces (constructions) or the erf boundaries unless these happen to coincide with the RRR boundary (van Oosterom *et al.*, 2011; Fisher & Whittal, 2020). A 2D cadastre employs the erf as its smallest spatial unit, while the LPO is the spatial unit of the 3D cadastre. The LPO may be restrictive or hold full ownership. Ownership LPO's may not overlap with each other, but restrictive LPO's may overlap with any other LPO's (van Oosterom *et al.*, 2011). "Rights in land are RRRs tied to the surface parcel, while rights in property apply to any RRRs in real property whether tied to the surface parcel or existing independently of it" (Humby, 2014: 5).

The record of real property rights held in the cadastre should be comprehensive and accurate, as it serves as evidence of the location and extent of those RRRs thereby securing tenure (Kaufmann & Steudler, 1998; Griffith-Charles & Sutherland, 2013; Humby, 2014; Paasch *et al.*, 2016; Humby & Whittal, 2017; Fisher & Whittal, 2020). It is accepted that increased tenure security promotes social equity, economic growth and sustainable development (Williamson *et al.*, 2010). To adequately secure tenure, the cadastre should wholly capture the reality of property RRRs to avoid unintelligibility in the record (Paulsson & Paasch, 2013; Humby, 2014; Humby & Whittal, 2017; Kitsakis *et al.*, 2018; Fisher & Whittal, 2020). Inaccuracy or obscurity in the cadastre can lead to confusion and disputes that may cost time and money.[4] The need for the introduction of 3D into the SA cadastre to benefit the first land administration function, land tenure, has been investigated using case studies within the CCT (Humby, 2014; Humby & Whittal, 2017). Humby (2014) concludes that a LPO approach may allow for the flexibility and comprehensiveness in records necessary to capture the increasing multiplicity of RRRs in SA.

1.1.3 THE PROPERTY MANAGEMENT OBJECT AND THE LAND ADMINISTRATION NEED

The remaining three land administration functions, land use, development and valuation, are achieved in 2D, based on the 2D cadastre, if spatial data is captured and used at all. However, accepting that RRRs are implied in 3D, one can accept that the PMS inadvertently and conceptually makes use of the LPO. Furthermore, the

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[3] A spatial object may have more than three dimensions. For example, the fourth dimension of time may be added to a rights object that will lapse after a period of time. This research is, however, immediately concerned with only 3D.

[4] See the Malawi House case study for an example of how a 3D record of RRRs may have saved the parties from a lengthy court process (Humby, 2014).

necessary (function-specific) non-registrable RRRs are appended to the LPO to create the theoretical Property Management Object (PMO).

The PMO is a combination of the registrable RRRs inherited from the cadastre in the form of the LPO and the non-registrable RRRs that stem from various sources that amend that LPO (see Section 5.3, Figure 1-1). As with the LPO, the PMO can be multi-dimensional, but is held fixed at 3D for this research's purposes. One can define the PMO based on the LPO definition given above as the multidimensional spatial object against which one or more unique and homogeneous property RRRs, registrable and non-registrable, are associated to the whole (object). The PMO or LPO may be situated at any vertical level (below, on or above the Earth' surface). It refers to the 3D RRR volume that may or may not align with the cadastral boundaries, consisting of developed or undeveloped space, in the air or underground, a physical construction, or a combination of these (Stoter, 2004).

1.1.4 3D LAND ADMINISTRATION

Most of the literature available regarding introducing 3D deals specifically with the 3D cadastre. However, van Oosterom *et al.* (2020) move away from the term 3D cadastre and instead adopt the term 3D land administration; it is more representative of the broad functions of a 3D model and the multi-disciplinary character of LAS. 3D land administration is supported by more than a 3D cadastre; it requires a comprehensive combination of the legal and the physical environments into a 3D data model or 3D city model (Aien *et al.*, 2013).

A 3D city model is "a representation of an urban environment with a three-dimensional geometry of common urban objects and structures, with buildings as the most prominent feature" (Biljecki *et al.*, 2015a: 2843). This study accepts this definition with the addition that a 3D city model is understood to be an extension of the 3D cadastre (that holds the LPO records). It is the collection of PMOs in a 3D data model of the urban environment. That data model may hold any amount of additional 3D information that is seen as necessary. In this research, the terms *3D GIS*, *3D data model*, *3D environment* and *3D city model* are used interchangeably[5] with the understanding that this study does not attempt to set a concrete definition for what the 3D environment should look like, but rather tries to answer whether that 3D data model is necessary within the SA LAS.

Furthermore, the Level of Detail (LOD) adopted for a 3D city model may differ when looking at different use cases (Biljecki *et al.*, 2015a). The Open Geospatial Consortium City GML standard defines five LODs that support differing application requirements and data collection techniques (2012). Biljecki *et al.* (2016a) extend this definition to 16 LODs. This research adopts this extended definition, as the CCT currently captures building models to a LOD2.2 in line with that definition (see 6.1.1i).

1.1.5 IN SUMMARY

The CCT, along with SA's other metropoles, is facing an unprecedented trend in urbanisation.[6] This is causing an increasing need for housing, service delivery, improved infrastructure, and environmental management. Therefore, there is an increasing need for improved land management, decision-making and property taxation. It is accepted that urban sprawl is unsustainable (Guo *et al.*, 2013) and, therefore, cities, including the CCT, are

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[5] As the terminology surrounding 3D cadastres and 3D city models has not been explicitly defined, there is a tendency in the literature to use different terms interchangeably (Biljecki *et al.*, 2015a).

[6] The Integrated Urban Development Framework ("IUDF", 2016) states that SA's urban population is estimated to grow from 60% to 71.3% by 2030, and to 80% by 2050.

promoting high-density, mixed-use development. To improve land administration, the property information held should be accurate, up-to-date and complete (Kurwakumire, 2014). Therefore, it should be asked whether the 2D cadastre provides sufficient data to achieve the land administration functions. Introducing a 3D PMO record may hold significant benefits to local government land administration, potentially increasing the accessibility, accuracy and relevance of property information. Consequently, it would support the necessary improvements to property management and decision-making in land development, use and valuation, to cope with the increasing complexity of the city.

A "well-functioning cadastre is essential for securing rights in land and property, wealth creation, and contributing to better land and environment management" (Jones & Land, 2012: 2). A cadastre is 'well-functioning' if it supports land administration goals of successful land tenure, use, development, and value, thereby achieving the end goal of sustainable development as set out by the land management paradigm (LMP) (Williamson *et al.*, 2010). Furthermore, the LAS should adhere to the principles of good governance. Ho *et al.* (2015) state that the increasing complexity of urban development and evolving RRR objects compound into ongoing land administration issues that will only deteriorate. The SA LAS is grounded on the 2D cadastre, but the functions it has to perform are inherently 3D in nature. This may result in the system not performing to its full capacity.

As societies evolve, so should legislation and the LAS and, if necessary, the concepts of ownership and property RRRs (Badenhorst *et al.*, 2006; Humby & Whittal, 2017). The SA cadastre may need to be adapted by adopting a 'broader non-parcel based approach' to the land administration functions (Williamson *et al.*, 2010) to handle the expected complexities in property RRRs, redefining the LAS as we know it. The first step is to establish whether there is a need for a PMO-based approach within the SA LAS. Without this there are no grounds for further research and development within the SA context. Previous research established that there is a need within the land tenure system (Humby, 2014). Whether there is a need for the introduction of a 3D RRRs tool to enable successful land and property management to fulfil the remaining three functions of land administration is investigated in this study.

Section 1.2 Research Formulation

1.2.1 THE RESEARCH PROBLEM STATEMENT

The cadastre forms the foundation of the LAS and its primary role is to provide an accurate, public and transparent record of property RRRs as per the good governance principles (GGP)(see 3.1.4). The 2D land parcel or erf is the basic unit of the SA cadastre and all property rights are tied to the parcel (Humby, 2014; Fisher & Whittal, 2020). However, as urban populations and the need for space increase, so does the development of complex property RRRs that become difficult to translate and manage in 2D and therefore may need to be recorded in their three-dimensionality (Atazadeh, 2017a; Biljecki *et al.*, 2015a; Stoter, 2004; Karki *et al.*, 2010; Ghawana *et al.*, 2019). This may require the adaptation of the LAS and the 2D-based cadastre to include 3D to effectively perform the required land administration functions; tenure, use, development and value (Enemark, 2005, 2006a; Williamson *et al.*, 2010; Karki, 2013; Enemark *et al.*, 2016) as discussed above. Humby (2014) presented the need for introducing 3D into the SA cadastre, with respect to the satisfactory accomplishment of tenure security. However, that research addressed only one of the four functions of land administration – land tenure.

Therefore, the research problem central to this study is:

South Africa is facing a future of increasing complexity in property objects and our ability to adequately record and manage these RRRs within the current LAS may be limited. This could adversely affect the land administration functions that depend on this record. The potential need to represent and manage property objects in 3D within the SA LAS has not been fully explored. Furthermore, there is a lack of research into the current state of the South African Property Management Systems (PMS) that are responsible for achieving the land administration functions of land use, development and value. Without an analysis of the current PMS, the need for a 3D LAS cannot be established and there can be no argument for or against the improvement of the cadastre and the LAS.

1.2.2 THE RESEARCH AIM

The potential implementation of a third dimension in the land administration system depends on the country-specific institutional context, the users' needs, the current legal framework, the property market needs, and the technical foundation and flexibility to reform (van Oosterom *et al.*, 2011; Ho *et al.*, 2013). Therefore, these areas would need to be investigated thoroughly and analysed for the potential introduction of 3D.

The principle aim of this study is to ascertain whether there is a need for, and the possible benefits of, introducing a third dimension into the SA land administration system. This analysis must be based on the current state of that LAS and the land administration functions of land tenure, use, development and value. The investigation as a whole can be divided into two key focus areas:

1. the land tenure system (LTS) and the Legal Property Object (LPO); and
2. the property management system (PMS) and the Property Management Object (PMO).

These two key areas fall within the SA LAS and make use of the cadastre as a foundation.

The first has been dealt with in Humby (2014) where it was found that there may be a need within the LTS and cadastre for 3D. This research is an extension of that study. In order to gain an understanding of the current state of the PMS, this research will examine the management, implementation, and the structures and processes surrounding the PMO within the CCT PMS and analyse whether the current 2D-based systems are compromising the successful achievement of the land use, development and valuation administration functions.

This examination leads directly to an analysis of any areas in the PMS that present a need for the third dimension. This discussion includes a study of the potential impact of introducing 3D on the CCT PMS and its capabilities to achieve the land administration goals, highlighting any potential benefits or risks that may arise. Established LAS theory, the LMP, RRRs and the GGP will guide this investigation. The research will indicate whether there is a need for the introduction of 3D into the LAS to deem further research and development necessary. The highly complex areas of the institutional[7] context and possible technical foundations of 3D LAS are not in the scope of this research, but could use this research as a foundation for future studies into these branches of the subject.

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[7] Socially and culturally accepted norms.

Section 1.3 The Research Questions

The research questions are as follows:

Considering the required land administration functions of the LAS, and the PMO, within a Property Management System (PMS) context:

1. what are the capabilities and limitations of the current CCT PMS to successfully achieve the goals of land use, development and valuation with respect to the PMO; and,
2. what could the benefits or impact on the capabilities of the CCT PMS to achieve the land administration goals be by introducing the third dimension in the form of the PMO?

Section 1.4 The Research Objectives

Aligning with the research questions, the first objective of this study is to understand the CCT Property Management System (PMS) using a single-case study design and systems modelling methods. The CCT PMS is adopted as the 'system-in-focus' (Beer, 1995). The SA LAS, its sub-systems, their relationships and functions have not been demonstrated to date, and this is not within the scope of this study. Rather a specific focus is maintained on the PMO and its movement, uses, management and life cycle within the PMS, resulting in a greater understanding of this sub-system of the greater LAS. This analysis includes a breakdown of the existing technical systems that support the management and dissemination of the PMO, and the legislation, regulations and policies that are relevant to PMO management or definition. The current state of the CCT PMS is evaluated against land administration theories adopted in Chapter 3, such as the LMP, GGP and RRRs. This analysis will aid an understanding of how the PMO, in its current simplified 2D format, is created, used, managed and transferred within the PMS and whether the CCT PMS successfully achieves the land administration functions and the goal of sustainable development. This analysis is essential to inform the discussion of whether 3D is necessary to the CCT PMS.

Following that, the research focus shifts to the third dimension. The second research objective is to analyse the benefits or impact introducing 3D may have on the capabilities of the PMS to achieve the land administration goals. Initially, the current use of 3D within the CCT PMS is investigated. Furthermore, the applications in which 3D adds value must be identified (Stoter et al., 2016b). Therefore, the potential uses, benefits and challenges that may be faced when introducing a third dimension are examined. The exploration will be informed by an analysis of the research and development taking place in the global arena with respect to introducing 3D RRRs into the LAS. This may provide confirmation that there exists a need for 3D within the CCT PMS and the greater SA LAS. Note that an in-depth analysis of the technical systems or technical solutions to introducing 3D are not within the scope of this research and are therefore excluded. This includes an analysis of other jurisdictions incorporation and management of the third dimension, as it does not add value to answering these research objectives.

Section 1.5 The Research Methodology

The research methodology and design is set out in Chapter 3 and Chapter 4. Cadastral systems research is by nature a combination of both qualitative and quantitative approaches, as it involves scientific and social elements inherently. Therefore, Mixed Methods Research (MMR) was adopted (see 3.2.4); combining varied methodologies to increase the validity and depth of the study's results (Maree *et al.*, 2007). The trouble with using a combination of these methodologies is their paradigms are at odds (Denscombe, 2008; Feilzer, 2010; Denzin, 2012; Hall, 2012). Pragmatism offers an alternative to these by at once accepting the existence of both a natural and social reality (Johnson *et al.*, 2004). Pragmatic research involves abductive reasoning and is focused on the study objectives (Feilzer, 2010). It allows for multiple research methods; supporting the choice of MMR (Ibid.). Therefore, a MMR strategy grounded in pragmatism is adopted in this study.

1.5.1 THE METHODOLOGICAL FRAMEWORK

The primary method adopted in this methodological framework is a single case study (see 3.3.1, Section 4.1) using semi-structured in-depth interviews (see 3.3.2, 4.2.3). To achieve the first objective of creating a model of the current CCT PMS and the flow of property information through that system, a single case study was performed focussed on the CCT PMS; the system-in-focus (Jackson, 2003). This method was deemed appropriate because the CCT PMS was identified as a unique system and single case studies are well-suited to analysing phenomena within the context in which they occur (see Section 4.1)(Yin, 2003). When employing the case study method, it is advisable to use multiple data sources, acquisition methods, data types and methods of analysis to improve triangulation and generalisability of results (Yin, 2003). This approach was applied here. The data collected included participant and direct observations, documentation and in-depth interviewing (see Section 4.2).

Data was collected using observation (see 4.2.2). The researcher has been employed within the CCT PMS since August 2018. Therefore, the researcher is a participant in the system-in-focus. Through her participation, she collects observation data on that system and the use of 3D data. In some instances, the researcher was actively involved in 3D use cases, likewise allowing for participant observation. Moreover, in her role, the researcher works with each department within the PMS and has the unique opportunity to learn about their individual aims, systems and ways of functioning. In this she is not participating in their subsystems; it is, therefore, direct observation data collection.

The documentation data (see 4.2.1) include CCT processes and policies; CCT organisation records, charts and organograms; relevant national and municipal legislation; webpages and press extracts; presentations, reports, meeting minutes, correspondence and memoranda. Furthermore, data on the current examples of 3D use cases was collected from existing Geographic Information Systems (GIS) projects, 3D models, pdfs and animations that have been produced for CCT use, along with maps, plans, the CCT Development Management Scheme (DMS)(2015) regulations and survey records. For the most part these documents are sourced from interviewees and through the researcher's position within the CCT.

Semi-structured in-depth interviews (see 4.2.3) were adopted to aid the exploratory aspects of this research; the outcomes could not be predicted because this is the initial research into both the CCT PMS and the possibility of introducing 3D. In-depth interviews are well-suited to this type of research (Dicicco-Bloom & Crabtree, 2006). They are guided conversations with a small number of participants that aim to gather perspectives on a particular phenomenon (Morris, 2015). The in-depth interviews were used to collect data to gain insight on the single case study, the CCT PMS, and the flow of property information and management of the conceptual PMO. Furthermore, interview data was collected to address the second research objective of the current and potential use of 3D within the CCT PMS. Initially, the obvious spatial data role-players within the PMS were identified as possible interviewees. Following this, the interviews were conducted using a snowball sampling approach; interviewee referrals were used to identify other informants, thereby expanding the pool of experts. The interviewees mainly consist of CCT staff, and include IT specialists, professional land surveyors, town planners, development management officials, valuations officials, property managers, Geomaticians, CCT managers from various departments and built environment academics.

The qualitative and quantitative data should be integrated in such a way as to extract patterns and meaning to answer the original research objectives of the study (Yin, 2003; Plano Clark & Ivankova, 2016). The methodological framework adopted (see Section 4.3) featured a pragmatic selection of case study and systems thinking analytical tools, including a case study database, a chain of evidence, data and method triangulation, within-case analysis, Soft Systems Methodology (SSM) rich pictures and Business Process Modelling (BPM) data flow diagrams. Pragmatically selecting a combination of parts of multiple methods can be successful in illustrating problem areas within a system (Whittal, 2008) such as the CCT PMS. The analysis was conducted in a reflective and repetitive manner, as the researcher moved constantly between the research questions, and the data collection and analysis phases, as new information was uncovered.

1.5.2 THE ANALYTICAL FRAMEWORK

The analytical framework consists of the various overlapping branches of land administration theory, including the land management paradigm (LMP), land administration theory, the good governance principles (GGP), and RRRs as defined in theory. (see Section 3.1, 4.3.4). These accepted best practice standards were used as a backdrop against which the capabilities and limitations of the current PMS with respect to managing the PMO could be diagnosed. Furthermore, the need for 3D and the possible consequences of introducing a 3D PMO record were weighed against the LAS theory – either bolstering or disagreeing with the data processed in this study. Data collected and processed was connected to relevant sections of the theory during the analysis process. Additionally, the analyses were informed by the literature reviewed on the international experiences in LAS and 3D cadastre or city models.

There is a potential for bias in both the use of in-depth interview data and the researcher being a participant in the system-in-focus (see Section 4.4). Any inherent biases within the research are likely to be nullified using triangulation between qualitative and quantitative methods (Whittal, 2008; Denzin, 2012; Plano Clark & Ivankova, 2016). Multiple data sources within a single-case study, as seen here, aid in increasing generalisability of the results (Denzin, 2012) and this was successfully illustrated in Whittal (2008).

Section 1.6 The Scope of the Research

This research is limited to an examination of the current state of the CCT Property Management System (PMS) focussed on the use and management of the Property Management Object (PMO). This will define the foundation to the investigation of the capabilities and limitations of the current PMS with respect successfully achieving the land administration goals. The legislation, technical and administrative processes that are relevant to the PMS and the PMO will be included in this exploration. Extensive interviews and 3D examples within the CCT PMS are employed to analyse any possible benefits that introducing a 3D record of RRRs could have. International research into drivers causing the move towards a 3D LAS, together with the PMS model (focused on the PMO) and the interviewee data will inform the analysis.

The research adopts the CCT as the system-in-focus. The land tenure system is a national responsibility and was analysed within the CCT in Humby (2014) and Humby and Whittal (2017). The property management system is a local government responsibility and therefore, each municipality has its own unique PMS. However, this research will analyse the PMS of one municipality, the CCT, an urban area facing one of the highest urban growth rates in SA. The results will be generalizable to other urban hubs, because local government legislation and processes are based on nationally defined legislation. The research is limited to the SA urban environment, because "modern cities not only change the way we live, they change our concept of land" (Williamson *et al.*, 2010: 43). Rural areas do not hold the complexities in property rights as are found in cities and a 3D tool may not be applicable. Rural areas have distinctive, complex issues that may require a different type of legal tool to solve.

The technical aspects of the current PMS are discussed in brief, only as far as is adding value to the model of that system or to illustrate the need for 3D within that system. An in-depth analysis of the technical aspects of the SA LAS and its sub-systems is not within the scope of this study. Additionally, the technical aspects behind introducing a third dimension are excluded from the scope of this research (technical aspects include data acquisition, GIS and Spatial Data Infrastructure (SDI) theory, database management systems, modelling tools and methods, exchange formats, to name a few). This would significantly add to the scope and breadth of the work, and cannot be tackled superficially. Therefore, it must be excluded from this study's scope. Similarly, the theoretical, legal and institutional aspects of upgrading a 2D system to a 3D digital environment are excluded from this study.

Insight into the 3D aspects of registrable RRRs that form the Legal Property Object (LPO) or the legal framework specific to the land tenure system are not included in this study. These have been introduced in Humby (2014) and, although there is more to be done, the LPO should be kept separate from the PMO when illustrating the need for 3D due to the separate nature of the systems that manage these property objects. For this reason, topics that fall outside local government jurisdiction and legislation, for example, mining rights, ambulatory boundaries or offshore property rights, are excluded from this study. The LPO and real property rights are treated as inherited as a source of information by the PMS in this study as per Figure 1-1.

This research does not take into account the entire solum.[8] Rather, the study looks to that space below, on or above ground that is capable of reservation for use or is developed. Thus, anything below a depth and above a height of development capabilities or use is excluded from this research. This would exclude any space inside the defined aviation-reserved zones for flight space.

As in Humby and Whittal (2017), the land surface is broken up into smaller planes, small enough to negate earth curvature, and allowing for the adoption of a planar assumption for the Earth's surface. Thus the third dimension discussed here is not a true 'z', but is rather orthometric height, 'h'. Therefore, the property representations would not be truly 3D, but are rather "2D plus 1D representations of 3D space" (Humby & Whittal, 2017: 2). It is likely that the 2D plus 1D property objects could deliver increased tenure security in much the same way as the 2D parcel-based records have up until now (Humby, 2014).

Section 1.7 The Plan of Development

This thesis consists of eight chapters designed to follow each other in a logical manner to present information collected and analysed, and to answer the research objectives in a conclusive manner. Chapter 1 is the introduction to the research formulation. The motivation and background are set out and the research design, research problem and aims are presented. Furthermore, the study objectives and the related research questions

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[8] See *Appendix A*.

are set out. Additionally, the chapter summarizes the research framework and concludes with the research scope, and the thesis structure.

Chapter 2, the literature review, presents research conducted on subjects that are pertinent to this research and the research objectives. It presents the motivation behind the drive to improve LAS, including urbanisation, the sustainable development goals (SDGs), an increasing complexity in property objects, silos that exist within the LAS and the goal of a multipurpose cadastre. Following this, the literature review moves on to research conducted on 3D LAS, the benefits and impact introducing 3D can have and the challenges 3D can bring about.

Chapter 3, the theoretical framework for LAS research, presents the relevant methodological and analytical frameworks that are pertinent to this research, including mixed methodology framework, pragmatism, single case studies, in-depth interviews, systems theory including soft systems methodology and business process modelling, reliability, generalisation, triangulation and the chain of evidence. Additionally, LAS theory is presented including the Land Management Paradigm (LMP), Land Information Systems (LIS), Spatial Data Infrastructure (SDI), good governance principles (GGPs) and Rights, Restrictions and Responsibilities(RRRs) that are adopted in this study as a theoretical foundation.

Chapter 4, the research design, sets out the adopted methodological and analytical frameworks based on the theory presented in Chapter 3. Mixed methodology grounded in pragmatism is adopted, because it incorporates a number of different research methods, to answer complex research questions in a holistic manner that has increased depth and validity. This is well-suited to LAS research. A single case study method is adopted to investigate the CCT Property Management System (PMS). The data collection techniques include documentation, participant and direct observation, and in-depth interviews. The analytical framework consists of within-case analysis, a chain of evidence, triangulation and systems-thinking tools, and a foundation of LAS theory.

Chapter 5 and 6 present the data processed in this research. Initially, Chapter 5 presents an overview of the SA LAS, including the LTS and the LPO. Following this, the technical foundation of the CCT PMS is described, including the sharing of property data. Furthermore, an in-depth investigation into, and a model of, the structures and processes of the CCT PMS that are focused on the lifecycle of the PMO is presented. The subsystems of the PMS are modelled (using SSM and BPM) according to the land administration functions and the management of the PMO. Chapter 6 sets out the current use of 3D and the PMO within the CCT PMS. Following this, the potential uses, benefits and challenges that introducing a third dimension may bring to the CCT PMS are presented, as drawn from the in-depth interviews, observational and documentation data.

Chapter 7, the data analysis, attempts to answer the research questions by discussing the data presented in chapters 5 and 6. The data is bolstered by the literature presented in chapter 2 and compared to the LAS theory adopted in chapter 4. Chapter 8 concludes the research by commenting on the adopted research methodology and theoretical frameworks, and presenting the conclusions and recommendations for further research.

Chapter 2 A REVIEW OF THE RELEVANT LITERATURE

This chapter presents a summary of the research produced on the necessary improvement of land administration systems (LAS), the concepts of multipurpose cadastres, 3D cadastres, LAS and city models, the experiences of implementing 3D and the applications, benefits or challenges encountered.

Section 2.1 State-of-the-art Land Administration Systems Research in SA

There is some research to be found that deals with South African land tenure and the Land Tenure System, as well as, land reform, rural land tenure and urban land markets – all of which are complex and weighty issues in the South African context. However, these subjects are not relevant to this study. There is a single paper analysing the potential use of LADM in the City of Tshwane (Tjia & Coetzee, 2013) and that paper notes that there is a shortage of research into land administration in a SA context. This study likewise found there is a severe lack of research into the current state of the SA Property Management System, as defined here, or the SA LAS as a whole including the land administration functions of land use, development and value. The PMS has not been investigated for any local government in SA, making this a ground-breaking study in its attempt to understand and model the CCT PMS. This research will present an initial exploration into this subject matter and, therefore, add important information into the state-of-the-art of the SA LAS and provide a foundation on which further research can be based.

Section 2.2 The Drivers of Change

2.2.1 THE SUSTAINABLE DEVELOPMENT GOALS

Rapid urbanisation is a reality faced globally and with it comes a range of socio-economic, governance and environmental issues (United Nations, 2015). As a result, the United Nations adopted 17 Sustainable Development Goals (SDGs) in 2015 that should be achieved by 2030. Specifically, SDG 11 requires the development of "inclusive, safe, resilient and sustainable" cities (Ibid.). Many of the other SDGs adopted fall within city management responsibilities too and effect urban development (Peinhardt, 2015; Corbett & Mellouli, 2017; Rabiee & Rajabifard, 2017). Therefore, a city plays a large role in achieving the SDGs and an integrated LAS is essential to that achievement (Enemark, 2005; Corbett & Mellouli, 2017). Additionally, the good governance principles (see 3.1.4) are essential to achieving sustainability (Bennett *et al.*, 2010).

2.2.2 NEW COMPLEXITY IN PROPERTY RRRS

Urbanisation is causing intensive densification and the emergence of new RRRs and interests in property, resulting in previously unseen complexity in volumetric property objects and the uses thereof (Stoter, 2004; Karki *et al.*, 2010). Faced with this reality, cities are under pressure to produce and maintain an up-to-date, complete and accessible record of property RRRs, land uses, infrastructure and the environment to successfully support the processes of land administration and sustainable development (Rajabifard & Ho, 2015; Indrajit *et al.*, 2018, 2020a). The city will experience a drive to capture as much information as possible about its spaces to facilitate improved decision-making across various fields (Rajabifard & Ho, 2015).

An effective RRRs record provides broad economic, political, environmental and societal benefits, thereby supporting sustainability (Rajabifard & Ho, 2015; Indrajit *et al.*, 2018, 2020a). The 2D land parcel within the cadastre is typically a common denominator of the LAS subsystems (Enemark, 2006a). Currently, this information is recorded independently in each subsystem, effectively duplicating the records (Kalantari *et al.*, 2008); leaving room for errors (Stoter, 2004). Furthermore, uncertainty in property records can lead to misunderstandings and conflict (Griffith-Charles & Sutherland, 2013). However, it is challenging to unambiguously capture complex 3D RRRs within the current 2D setting (Guo *et al.*, 2013; Atazadeh *et al.*, 2016b) and a lack of clear geometry in property records negatively affects the land administration functions (Stoter, 2004; Shoshani *et al.*, 2005; Ho *et al.*, 2013; Bakken & Øverli, 2016; Atazadeh *et al.*, 2016b).

2.2.3 THE SILOS WITHIN THE LAS

There are four recognised primary functions of the LAS: (i) land tenure; (ii) land use; (iii) land development; and (iv) land valuation (Kalantari *et al.*, 2008; Williamson *et al.*, 2010; Karki, 2013; Enemark *et al.*, 2016; Enemark, 2006a). The LAS functions are supported by the cadastre (Williamson *et al.*, 2010a; Enemark, 2005; Jones & Land, 2012; Radulović *et al.*, 2017) and, although the cadastre's primary function is to capture the legal condition of land, land use, development and value are dependent on the cadastral records (Karki, 2013; Isikdag *et al.*, 2015).

The land administration functions are typically handled at different levels of government, increasing the need to have an easily accessible, up-to-date, consolidated record of property RRRs (Stoter, 2004; Enemark, 2005). However, these subsystems have, typically, developed independently, each focussed on their own administrative role and, therefore, developing to best serve their own purpose (Kalantari *et al.*, 2008). The result is the creation of separate silos that cannot communicate or interoperate because of their unique design and the use of unique identifiers (Ibid.). Poor administration processes aggravates this separation (Enemark, 2006a). This negatively affects the LAS sustainability, flexibility and efficiency (Kalantari *et al.*, 2008).

An effective LAS should have cooperation between the separate LAS subsystems (Rajabifard & Ho, 2015). This requires the standardisation of information and practices to promote successful data flows between stakeholders (van Oosterom, 2013). The LAS should focus less on individual core functions of the subsystems and rather transform into an integrated system that centres on a comprehensive and interoperable data model that holds all property information and is reliable, up-to-date and accurate (Indrajit *et al.*, 2020b; Enemark *et al.*, 2005; Kalantari *et al.*, 2008; Kurwakumire, 2014). To achieve this, the subsystems of the LAS and the elements of each subsystem's data models should be identified and analysed to allow for the reengineering of the LAS (Kalantari *et al.*, 2008). It is important to analyse both the administrative and technical structures of the LAS subsystems to successfully introduce a modern, integrated LAS focussed on the property object (Paasch *et al.*, 2016).

2.2.4 A MULTIPURPOSE CADASTRE AND LAS

A modern LAS can establish "effective land use management" through the successful implementation of the land administration functions thus supporting sustainable development (Enemark, 2006a: 8). In order to achieve the land administration functions, the cadastre should adopt a multipurpose utility (Williamson *et al.*, 2010). A multipurpose cadastre is "a framework that supports continuous, readily available, and comprehensive land-related information" (National Research Council (NRC), 1980: 1). It is an "integrated land information system" and supports all four land administration functions (Williamson *et al.*, 2010; Jones & Land, 2012; Reicken & Seifert, 2012; Choon & Seng, 2014: 9; Roić *et al.*, 2017), as well as improved communication and public participation, increased data quality, accessibility and consistency, integration of all available property and geographic data, deeper analysis capabilities, and improved transparency in the LAS (Enemark, 2006b; Jones & Land, 2012).The information held should include the property's physical character (including the topography, building(s), infrastructure and utility networks), the real rights attached to the property, the land use and development RRRs, and the property value (Choon & Seng, 2014). Geographic Information Systems (GIS) support this functionality and form the core of a multipurpose cadastre (Jones & Land, 2012).

Section 2.3 Land Administration and 3D Data

Urbanisation has been identified as a significant reason to introduce 3D into the cadastre and LAS due to an increasingly high-density, mixed-use urban landscape (Stoter, 2004; Valstad, 2006; Karki *et al.*, 2010; Rajabifard & Ho, 2015). Furthermore, an increase in property density results in an increased complexity in, and load on, the urban utilities and infrastructure that are required to service these areas (Rajabifard & Ho, 2015). A 3D data model provides a means for understanding the complexity of the modern-day urban environment (Rajabifard & Ho, 2015; Stoter *et al.*, 2016a) by providing a holistic and integrated view of the land administration functions (Indrajit *et al.*, 2018).

The introduction of the third dimension is not limited to the cadastre; 3D may be introduced into the LAS as a whole, including the Property Management System (PMS) and city management (van Oosterom *et al.*, 2020; Biljecki *et al.*, 2015a). The introduction of 3D should not exclude the functions of land use, development and value, because these contain inherently 3D aspects and tasks (van Oosterom, 2013). A 3D cadastre can support all four land administration functions within the LAS, as well as improving planning and decision-making, and acting as a foundation layer for other spatial data layers such as land use or utility networks in a 3D city model[9] (Aien *et al.*, 2013; Rajabifard & Ho, 2015; Neuville *et al.*, 2018). Therefore, a 3D property record is seen as a necessary, and feasible, solution to land administration in a time of intensive densification caused by urbanisation (Guo *et al.*, 2013).

The integration of the LAS subsystems should include a 3D cadastre as the primary component (Wallace & Williamson, 2006; Rajabifard & Ho, 2015; Hajji, 2018). A 3D city model should integrate a 3D cadastre (LPOs) to non-registerable RRRs and the built environment (creating PMOs) to be successful (Indrajit *et al.*, 2020b; Bydłosz *et al.*, 2018; Hajji, 2018). Furthermore, the uses of a 3D city model are thought to be extended considerably by attributing non-spatial datasets to the spatial objects (Billen *et al.*, 2014; Stoter *et al.*, 2020).

There should be a strategic implementation of 3D; not all information should necessarily be represented in 3D to be useful and different LODs may be adopted for different purposes (Biljecki *et al.*, 2015a; Bydłosz *et al.*, 2018; Tang *et al.*, 2020). Furthermore, almost every 3D city model application requires slightly different data models and tools (Biljecki *et al.*, 2015a; *et al.*, 2010; Ellul & Altenbuchner, 2014; Saran *et al.*, 2015). Therefore, 3D city models should be generated using a “fit-for-purpose” approach (Biljecki *et al.*, 2015a: 2843).

The developments countries have made are unique to their situation and depend significantly on each country’s existing LAS (Stoter, 2004). However, it is essential that a city looks to international experiences and established standards when designing their 3D approach (Ghawana *et al.*, 2020). The literature is vast and varied, and more has been written on the benefits than on the challenges experienced when introducing 3D. It is important to thoroughly evaluate the potential benefits versus the potential costs of introducing 3D (Shepherd, 2008; Griffith-

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[9] As defined in 1.1.4.

Charles & Sutherland, 2013; Wong, 2015; Vučić *et al.*, 2017; Hajji, 2018; Larsson *et al.*, 2020), although it may be difficult to place monetary value on some of the benefits (Griffith-Charles & Sutherland, 2013). Furthermore, it has been noted that it is vital to analyse the potential of a 3D approach to create public value[10] (Ho *et al.*, 2018).

Section 2.4 Possible Benefits 3D can offer Land Administration

A 3D city model would have significant benefits in the wider LAS including in planning, management, economic and social contexts (Paulsson & Paasch, 2013; Stoter et al., 2020; Coote et al., in press) as demonstrated in research over the past two decades (Dimopoulou *et al.*, 2018). As early as 2000, Batty *et al.* (2000) identified 12 sectors that were making use of 3D city models. Biljecki *et al.* (2015a) used that as a foundation for their work and found that 3D city models had thus far provided over 100 applications. Furthermore, Wong (2015) listed 20 3D use cases.

Although visualisations are viewed as the predominant benefit, there are many other uses that are coming to the fore as 3D models are adopted by a broader market (Guney, 2016; Biljecki *et al.*, 2015a). Swisstopo, the Swiss Federal Office of Topography, found that before 3D was introduced, people could not conceive of the benefits it could offer. However, once a 3D system was running and accessible, their clients were satisfied that working in that environment is beneficial (Coumans, 2019).

2.4.1 POWERFUL INFORMATION MANAGEMENT TOOL

i EVIDENCE-BASED DECISION-MAKING

A 3D city model supports evidence-based decision-making, fore-casting and strategizing for improved urban management (Rajabifard *et al.*, 2018a; Sabri *et al.*, 2015a; Lenin Barath Kumar *et al.*, 2014; Billen *et al.*, 2015; Rajabifard & Ho, 2015). It supports the integration of multidisciplinary datasets (Buyukdemircioglu & Kocaman, 2020) that can be used for many different applications, improving data consistency (Saran *et al.*, 2018), accuracy, reliability and accessibility, and saving resources (Vučić *et al.*, 2017), while decreasing the risk of storing ambiguous and erroneous data (Rajabifard & Ho, 2015).

ii URBAN PLANNING: VISUALIZING THE IMPACT

It has been found that 3D city models have a significant impact on improving urban planning and development processes (Buhur *et al.*, 2009; Navratil & Fogliaroni, 2014; Seifert *et al.*, 2016; Chundeli, 2017; Coote *et al.*, 2017; Bydłosz *et al.*, 2018; Indrajit *et al.*, 2018; Neuville *et al.*, 2019; Saeidi *et al.*, 2019; Schrotter & Hürzeler, 2020; Sabri *et al.*, 2015a). A 3D environment provides an improved understanding of the existing and the proposed urban landscapes (Seifert *et al.*, 2016; Coote *et al.*, 2017; Sabri *et al.*, 2015a) and the spatial arrangement of complex property objects within their environment (Ghawana *et al.*, 2020; Atazadeh, 2017a; Biljecki *et al.*, 2015a).

A 3D environment supports informed decision-making, urban planning and policy determination by allowing for the visualisation of the impact of development on the current urbanscape (Saeidi *et al.*, 2019; Schrotter & Hürzeler, 2020). It can be used to visualise the long-term development plan by overlaying the current built environment, proposed developments and the desired urban landscape (Schrotter & Hürzeler, 2020). Additionally, a 3D city model can support the protection of natural, culturally-significant and heritage spaces. A 3D city model can be

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[10] See Appendix A.

used to visualise the impact of urban development on important landscapes and landmarks, while involving more stakeholders in a participatory decision-making process (Saeidi *et al.*, 2019; Tezel *et al.*, 2019).

iii IMPROVED LAND USE AND DEVELOPMENT PROCESSES

Land use and development regulations place restrictions on the property and determine the vertical extent and use of property objects (Indrajit *et al.*, 2020b). Therefore, it is vital that these are included in both the 3D cadastre and the 3D city model to capture a complete picture of the RRRs (Kitsakis & Dimopoulou, 2016; Indrajit *et al.*, 2020a). Coote *et al.* (in press) found introducing 3D into the land use and development approval processes improved efficiency and decreased the overall costs for both the City and the developers and greater public. To this end, Norwegian municipalities are developing a 3D land use management system that includes 3D development envelopes[11] to increase the effectiveness of the development processes (Bakken & Øverli, 2016).

Herbert & Chen (2015) present the apparent benefits of 2D versus 3D visualisations in the context of urban planning and found that planners' preference of 2D or 3D was task-dependent. The more complex planning tasks were assisted by an interactive 3D visualisation that allowed for multiple viewpoints and the context of a development. However, simple tasks, like measuring setbacks, were more difficult in 3D (Ibid.).

iv BETTER PUBLIC ENGAGEMENT

An integrated and interactive 3D city model improves communication and collaboration with a broader audience (Chundeli, 2017; Dembski *et al.*, 2020; Schrotter & Hürzeler, 2020; Atazadeh, 2017a) and this increases public value (Ho *et al.*, 2018). Transparency in the LAS is improved by allowing for a visualisation of RRRs as they stand in reality (Paasch *et al.*, 2016; Vučić *et al.*, 2017), communicating complex situations more effectively than 2D maps (Shepherd, 2008; Skarbal *et al.*, 2017; Larsson *et al.*, 2018; Dembski *et al.*, 2020). The majority of people struggle to make sense of 2D maps and plans. 3D is seen as more accessible because it presents a familiar viewpoint, it increases volumetric understanding, is easily interpreted for size, relation and orientation, supports navigation and is imaginative (Rajabifard *et al.*, 2018b; Nielsen, 2005; Shepherd, 2008; Bakken & Øverli, 2016; Fisher-Gewirtzman, 2018). Therefore, it reduces the potential for misunderstandings or conflict in urban management processes (Guo *et al.*, 2013) and supports participatory decision-making (Ghawana *et al.*, 2020; Schrotter & Hürzeler, 2020). A 3D city model of Herrenberg, Germany, tested positively with the public and was seen to improve communication and to "democratize urban data" (Dembski *et al.*, 2020: 15).

2.4.2 BROADER ANALYTIC CAPABILITIES

The improved spatial analysis methods that a 3D model offers carries huge potential (Kurakula & Kuffer, 2008; Billen et al., 2015; Beil & Kolbe, 2017; Biljecki et al., 2015a) and this has been recognised as having public value (Ho *et al.*, 2018). The following are examples of 3D spatial analysis but this list is not exhaustive.

i POPULATION ESTIMATES

It has been shown that estimating the population of an area based on 3D volumetric building data is more accurate than estimations calculated using 2D building footprint data (Biljecki *et al.*, 2016b; Lu *et al.*, 2011). This offers a cheaper, faster alternative to census data population estimates; although a census is still more accurate

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[11] As defined in 5.4.3.5.3.3ii.

(Biljecki *et al.*, 2016b). Population estimates are useful for emergency response scenarios (Biljecki *et al.*, 2015a) and for predicting the future utility and infrastructure needs in an area (Rajabifard *et al.*, 2018a).

ii ENERGY DEMAND ANALYSIS

The estimation of current and future energy demands in an urban environment is dependent on the 3D volume of existing and planned buildings, making a 3D model essential to this analysis (Kaden & Kolbe, 2014; Nouvel *et al.*, 2014; Wate *et al.*, 2016; Skarbal *et al.*, 2017; Yamamura *et al.*, 2017). The estimation informs the current usage and can be used to predict future energy infrastructure requirements (Krüger & Kolbe, 2012; Nouvel *et al.*, 2013; Kaden & Kolbe, 2014; Braun *et al.*, 2018; Biljecki *et al.*, 2015a). 3D city models are shown to be vital to in-depth climate change analyses that inform the development of green energy strategies that serve the sustainable development goals (SDGs)(Nouvel *et al.*, 2013; Benner *et al.*, 2016; Skarbal *et al.*, 2017; Schrotter & Hürzeler, 2020).

A 3D city model provides a suitable foundation on which to conduct urban solar potential analyses (Biljecki *et al.*, 2015b; Hofierka & Zlocha, 2012; Jakubiec & Reinhart, 2013; Fath *et al.*, 2015; Liang *et al.*, 2015; Li *et al.*, 2015; Saran *et al.*, 2015; Verso *et al.*, 2015; Wate *et al.*, 2016; Romero Rodríguez *et al.*, 2017). Estimating the solar potential of an urban environment to install photovoltaic panels is important to decrease traditional energy dependence and lower CO_2 emissions, thus supporting policy makers and increasing sustainability (Hofierka & Zlocha, 2012; Jakubiec & Reinhart, 2013; Romero Rodríguez *et al.*, 2017).

Related to the analysis of solar potential is shadow analysis. Shadow analysis is used to determine both the solar potential of buildings and the effect of a building's shadow on the neighbourhood's access to natural sunlight (Biljecki *et al.*, 2015a). It was seen as a benefit of 3D visualisations by urban planners (Herbert & Chen, 2015).

iii DISASTER MANAGEMENT ANALYSIS

3D GIS has been shown to be useful to disaster management (Zlatanova *et al.*, 2004; Kemec *et al.*, 2010; Ghawana *et al.*, 2019; Emamgholian *et al.*, 2020) and in particular, flood management (Roy & Coors, 2011; van Ackere et al., 2016; Leskens et al., 2017; Coote et al., in press). This includes the simulation of potential flooding and the effects thereof for disaster preparedness, public awareness and decision and policy making (Reyes & Chen, 2017; Kumar *et al.*, 2018; Bazan-Krzywoszańska *et al.*, 2019). A 3D flood data model provides a more relatable and realistic visualisation (Reyes & Chen, 2017; Kumar *et al.*, 2018) and a survey found that participants understood a 3D flood model better than a 2D representation of the potential flood (Leskens *et al.*, 2017). Additionally, a 3D analysis of flood plains was found to better inform urban development policies (Buyuksalih *et al.*, 2019).

iv NOISE POLLUTION

There have been several investigations into 3D noise mapping and mitigation (Kurakula & Kuffer, 2008; Stoter *et al.*, 2008; Law *et al.*, 2011; Herman & Řezník, 2013; Zhao *et al.*, 2016; Kumar *et al.*, 2017; Lu *et al.*, 2017). A 3D city model has been found to calculate a more reliable estimate of noise pollution and its propagation in urban environments than is possible with a 2D dataset; traditional 2D noise maps fail to accurately represent the 3D nature of noise and therefore, cannot accurately predict the effects thereof (Stoter *et al.*, 2008; Law *et al.*, 2011; Kumar *et al.*, 2017; Lu *et al.*, 2017; Jovanović *et al.*, 2020). A 3D noise model provides an easy-to-understand representation of data that can be used by decision-makers for urban planning (Kurakula & Kuffer, 2008; Kumar *et al.*, 2017).

v SECURITY AND CRIME MAPPING

Research has been conducted on the mapping and analysis of crime incidence using a 3D city model (Lenin Barath Kumar *et al.*, 2014; Park *et al.*, 2019). These studies showed that the traditional 2D crime maps are not successfully capturing the true spatial nature of crime incidence in complex urban environments and that a 3D data model is imperative to the planning and design of safer urban environments (Ibid.). Furthermore, a 3D environment can be used to promote security and public safety. 3D GIS can be used to optimize surveillance cameras positioning (Biljecki *et al.*, 2015a) and the use of 3D visibility analysis of public safety risks in an area has been shown to be beneficial (Aleksandrov *et al.*, 2019).

2.4.3 IMPROVED MAPPING AND MANAGEMENT OF INFRASTRUCTURE

The mapping, security and management of utility and transport infrastructure are improved by the inclusion of 3D data (Biljecki *et al.*, 2015a; Rajabifard *et al.*, 2018a; Sabri *et al.*, 2015a; Batty *et al.*, 2000; Wong, 2015; Paasch *et al.*, 2016; Pouliot & Girard, 2016; Beil & Kolbe, 2017; Vučić *et al.*, 2017; Labetski *et al.*, 2018; Yan *et al.*, 2019). Improved infrastructure design, planning and accuracy in engineering works are listed as drivers for introducing 3D (van Son *et al.*, 2018; Ghawana *et al.*, 2020). Additionally, the inherent "inefficiencies, costs and risks" associated with underground utility management could be significantly reduced by the introduction of 3D (Threlfall, 2018: 1). Furthermore, a 3D model could ease the complex and lengthy process of gaining permission from local authorities to conduct non-emergency roadworks (Ibid.).

2.4.4 INCREASED ACCURACY OF PROPERTY VALUE CALCULATIONS

Property valuation determines real property tax and this revenue is an important source of government income (Isikdag *et al.*, 2015). Therefore, this value should be calculated as accurately as possible (Ibid.). It is acknowledged that 2D GIS cannot provide a sufficient understanding of the 3D nature of property for valuation purposes (Yamani *et al.*, 2019). A 3D data model can increase the accuracy of property value calculations (Sabri *et al.*, 2015a); this being a major driver for introducing a 3D LAS in Delhi (Ghawana *et al.*, 2020). Additionally, China has recognised that 3D is vital to determining a property's market value and larger municipalities have adopted 3D data models to improve valuation processes (Ying *et al.*, 2019).

The value of a property is typically dependent on a number of parameters that are estimated using various field and remote survey methods (Isikdag *et al.*, 2015). To improve the property value calculation, the computation of these parameters should be as fair and accurate as possible (Ibid.). The highest weighted parameter in a property value calculation is typically the floor area (Ibid.). However, the usable area or volume of a property object can be extracted from a 3D record more accurately (Boeters *et al.*, 2015; Isikdag *et al.*, 2015; Atazadeh *et al.*, 2017b).

Additionally, the 3D location of a property determines important characteristics[12] that contribute to a property's value (Tomić *et al.*, 2012; Navratil & Fogliaroni, 2014; Yamani *et al.*, 2020). A property object's view (Tomić *et al.*, 2012; Ying *et al.*, 2019), property orientation (Ying *et al.*, 2019), access to sunlight (Li *et al.*, 2019; Ying *et al.*, 2019), the sky-view factor (Liang *et al.*, 2017; Ying *et al.*, 2019), indoor illumination (Saran *et al.*, 2015), building insulation and thermal comfort estimates (Biljecki *et al.*, 2015a) are all 3D characteristics that affect a property's value. Furthermore, by visualizing a 3D data model one gains an indication of the building location, type and quality to

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[12] Refer to Yamani *et al.* (2020: 12) for a full summary of 3D characteristics that determine a property's value.

add further parameters into the valuation (Isikdag *et al.*, 2015). These characteristics can be included in mass appraisal processes to significantly improve property value calculations (Tomić *et al.*, 2012; Zhang *et al.*, 2014).

2.4.5 STIMULATING THE ECONOMY

Introducing a 3D property object increased the possibility of construction financing in Sweden, especially for large and complex developments (Paulsson & Paasch, 2013). This encouraged growth in the construction and property markets, and resulted in an increase in employment in those sectors. This may bring about an increase in the property tax revenue in future (Ibid.). Furthermore, Norway introduced 3D property objects with the aim to provide secure tenure to attract investment, thereby stimulating development and the property market (Onsrud, 2003).

Section 2.5 The Possible Challenges of Introducing 3D

Although there is more written on the uses of a 3D city model than the challenges faced when introducing 3D, it is noted that 3D city models, in general, do not live up to the envisioned applications (Julin *et al.*, 2018).

2.5.1 THE INSTITUTIONAL CHALLENGES

Although a city's interests lie in multi-dimension data, urban administration is still based on 2D. This reliance on traditional 2D systems limits the improvement of that system, keeping progress at bay (Ho *et al.*, 2013). If a current LAS is accepted as adequate and reliable, it becomes difficult to argue that this working system be replaced by something new and unknown, even if the legislation is changed to support the change (Ho *et al.*, 2013; Ho & Rajabifard, 2016). Therefore, the real challenge lies in changing the institutional culture that forms the backbone of how we approach property rights (Ibid.).

The introduction of 3D requires significant institutional change to adapt to working in the new 3D environment (Guo *et al.*, 2013). The necessary legislation and regulatory support should be introduced to provide a stable foundation for the introduction of 3D to prevent a haphazard introduction (Ghawana *et al.*, 2020). Furthermore, there is typically a lack of skills, resources and capacity that should be addressed (Ho & Rajabifard, 2016). This adaption period may cause frustration as the processes slow down while people learn to work in 3D (Guo *et al.*, 2013). Therefore, the legitimacy of the project should be increased by institutional and political buy-in at every level to ensure a 3D environment succeeds (Wallace & Williamson, 2006; Griffith-Charles & Sutherland, 2013; Ho & Rajabifard, 2016). Additionally, educating the public is important when introducing a 3D system (Bakken & Øverli, 2016; Purkait & Das, 2018).

2.5.2 THE DISPARITY BETWEEN THE PHYSICAL AND LEGAL PROPERTY INFORMATION RECORDS

Even though there has been much research on 3D LAS and city models, there is no solution that supports both the legal and physical objects (Atazadeh *et al.*, 2017b; Rajabifard *et al.*, 2018c; Aien *et al.*, 2013). These datasets are typically held in separate registers or databases. This can be attributed both to a continued reliance on 2D parcels as the foundation of the cadastre and LAS, and technological limitations in capturing and managing this type of information (Aien *et al.*, 2013; Atazadeh *et al.*, 2017b).

There exist spatial databases that contain the 3D Property Management Object (PMO) record in the form of Building Information Modelling or CityGML or CAD, but these do not integrate the legal object. Similarly, the

3D Legal Property Object (LPO) has been captured in cadastral systems in countries such as the Netherlands, but the physical PMO is not recorded (Stoter, 2004; Aien *et al.*, 2013). Only by integrating the legal and the physical objects will the full functionality and benefits of a 3D data model be realised (Rajabifard *et al.*, 2018c; Aien *et al.*, 2013; Kalogianni *et al.*, 2017; Van Oosterom *et al.*, 2018).

2.5.3 MAINTAINING UP-TO-DATE DATASETS

The benefits that a 3D city model can bring may never be seen if there is not continuous system maintenance to maintain accurate and up-to-date datasets (Griffith-Charles & Sutherland, 2013; Buyukdemircioglu & Kocaman, 2020). It was found that 3D city models are often built and introduced without an adequate maintenance strategy that ensures the model is kept up-to-date (Stoter *et al.*, 2020). Maintaining up-to-date datasets is the biggest challenge in maintaining a 3D system and it has broad knock-on effects on the applications of 3D data (Cappelle *et al.*, 2012; Alatalo *et al.*, 2016; Coumans, 2019). Furthermore, 3D city model users are more sensitive to out-of-date data because the model can be easily associated with the real-world (Billen *et al.*, 2015). A possible, partial solution would be to require new developments to be submitted in a standard 3D model format for inclusion into the 3D environment (Stoter *et al.*, 2020).

2.5.4 LIMITATIONS IN CURRENT TECHNOLOGY

The technical creation and sharing of 3D city models is highly challenging (Lenin Barath Kumar *et al.*, 2014; Purkait & Das, 2018). The existing IT infrastructure of an organisation is a large hurdle to introducing 3D (Wallace & Williamson, 2006; Purkait & Das, 2018; Coumans, 2019) as well as the limited alternatives on the market (Guney, 2016; Stoter *et al.*, 2020); there is a lack of user-friendly 3D analysis tools (Janečka & Karki, 2016). Often the available technology is demonstrated and tested on a small area and when applied to a whole city using real-world data, the software is found lacking (Ibid.). This is especially true when moving beyond visualisations and into 3D spatial analytics (Ibid.). For example, it has been found that ESRI Arc Scene has limited capabilities in handling larger datasets and other software solutions will be required to support a 3D environment (Emamgholian *et al.*, 2020). Furthermore, it is noted that the currently available tools have to be improved to allow for better integration of spatial and non-spatial data (Chundeli, 2017) and the necessary LOD to accommodate different property objects (Sabri *et al.*, 2015a).

2.5.5 THE EXPENSE AND RESOURCES NECESSARY TO INTRODUCING 3D

In China, only the larger municipalities have adopted 3D approaches to valuations and land use management due to the high expense (fiscal, human and technological) associated with a 3D system (Ying *et al.*, 2019). The data acquisition, processing and development necessary to implement a 3D city model is expensive and resource-hungry (Saran *et al.*, 2018; Buyuksalih *et al.*, 2019) although technological improvements are reducing these costs every year (Coote et al., in press). When employing "rapid data acquisition" techniques for 3D city model production, the validation and integration with the established LAS becomes challenging, if not impossible, to automate (Dimopoulou *et al.*, 2016: 125). 3D data validation is far more complex than in 2D (Saran *et al.*, 2018). Moreover, complex buildings require manual intervention; costing time and human resources (Buyuksalih *et al.*, 2019). Additionally, the mapping of underground infrastructure has been found to be costly and complex, even with the significant improvements in data collection technologies (van Son *et al.*, 2018).

The computational costs of running analyses on 3D data models is far higher than on 2D datasets; the greater the number of 3D building models, the higher the hardware and software requirements are (Liang *et al.*, 2015) and the sooner the visualisation limit is reached (Shepherd, 2008). Additionally, the higher the LOD adopted, the greater the data collection, storage and serving costs (Biljecki *et al.*, 2017). However, a higher LOD does not always result in better analyses and therefore the increased costs are not justified (Shepherd, 2008; Biljecki *et al.*, 2017). Therefore, an evaluation of what 3D data should be employed and when, is necessary (Shepherd, 2008).

2.5.6 A NEED FOR COLLABORATION

Silo's within the LAS are acknowledged as a large hurdle for system modernisation (Krigsholm *et al.*, 2018). Inconsistencies in data collection, processing, management and dissemination, resulting from silos within the LAS, lead to incompatible data models and this is especially apparent in 3D (Stoter *et al.*, 2020). Furthermore, a lack of a defined vocabulary, concepts and a paradigm for 3D city models can result in miscommunication, reinforcing those silos (van Oosterom, 2013; Billen *et al.*, 2015). To sustainably manage and plan for the future high-density urban space, multidisciplinary collaboration in the LAS should be implemented and government, business and the public will be required to collaborate to optimize land administration (Purkait & Das, 2018; Atazadeh *et al.*, 2016b).

Collaboration, integration and interoperability are brought about by standardisation of datasets and processes (Billen *et al.*, 2015; Indrajit *et al.*, 2020a). This is required to achieve a successful 3D city model, ensure data consistency and to realise the full benefits of 3D (Saran *et al.*, 2018; Stoter *et al.*, 2020; Sabri *et al.*, 2015b). Integrating the necessary property information will reduce redundancy, save resources and enhance data quality and security (Vučić *et al.*, 2017). Introducing interoperability between different existing IT systems and workflows will be a major challenge (Billen *et al.*, 2015; Purkait & Das, 2018).

Standardisation can be achieved by restructuring the foundation of the LAS to capture all RRRs of each PMO into a single cadastral record, thereby avoiding duplication of datasets in the different LAS subsystems (Indrajit *et al.*, 2020b). The CityGML standard provides a practical and customizable foundation for the standardizing and sharing of 3D datasets (Krüger & Kolbe, 2012; Aditya & Laksono, 2017; Buyukdemircioglu & Kocaman, 2020; Ghawana *et al.*, 2020; Stoter *et al.*, 2020). However, it is noted that there is limited support for CityGML (Stoter *et al.*, 2020). Furthermore, the definitions of CityGML[13] LOD are not accommodating enough (Boeters *et al.*, 2015). It is noted that the optimal LOD may not be the highest LOD (Shepherd, 2008; Biljecki *et al.*, 2017; Tang *et al.*, 2020). For example, a highly detailed 3D city model is less useful for land use planning purposes than a simple 3D representation (Bakken & Øverli, 2016).

2.5.7 DATA QUALITY CONCERNS

There are concerns around data quality in 3D city models and how this adversely affects the benefits and sharing capabilities (Billen *et al.*, 2015; Stoter *et al.*, 2020; Biljecki *et al.*, 2016c). It is essential that the integrity of a 3D dataset is ensured by performing geometric and semantic data validations (Kalantari *et al.*, 2017). It was found

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[13] CityGML is an open standard and is defined in *Appendix A*.

that most existing 3D CityGML models contain many geometric errors (Biljecki *et al.*, 2016c). Unfortunately, there is a lack of research into concrete methods of 3D objects validation (Ibid.). Furthermore, high quality metadata is of utmost importance to support reliable decision-making (Schrotter & Hürzeler, 2020).

2.5.8 MISPLACED CONFIDENCE IN 3D

The variable scale in a 3D environment presents a risk of occlusion and perspective issues in 3D visualisations and this makes it challenging to present a truthful comparison of different objects in a 3D model (Shepherd, 2008; Neuville *et al.*, 2019). However, people disregard these risks because a 3D perspective seems more familiar and trustworthy than a 2D representation (Ibid.). Neuville *et al.* (2019) recommend the creation of pre-set viewpoints that are automatically navigated to when exploring a certain 3D use case to reduce these risks. Furthermore, a realistic 3D model could exaggerate public expectations of proposed developments (Nielsen, 2005).

2.5.9 AN EXCLUSIONARY, TECHNOCRATIC SOLUTION

The introduction of a fully 3D LAS may be held back by concern over possible negative social consequences (Paulsson & Paasch, 2013). A 3D approach creates a risk of segregation between those persons who can afford to use it and those who cannot (Ibid.). Those who do not have access to the technology or professional assistance, due to financial or social limitations, are left in a state of helplessness. This increases the risk of exclusion from, and possible gentrification of, urban spaces (Ibid.).

All city stakeholders have the right to access complete and accurate land administration records that fully encompass all property RRRs (Indrajit *et al.*, 2020a). A 3D city model should be publically accessible and user-friendly to ensure equitable benefits to all (Schrotter & Hürzeler, 2020; Indrajit *et al.*, 2020a). This is necessary to achieve sustainable development (Indrajit *et al.*, 2020a) and active public participation (Schrotter & Hürzeler, 2020).

2.5.10 DATA PROTECTION AND PRIVACY CONCERNS

There are ethical concerns about the LOD of a 3D city model and the data protection, privacy and the accessibility of that information (Billen *et al.*, 2015; Purkait & Das, 2018; Sabri *et al.*, 2015a). A 3D city model is more accessible to a broader public, increasing the privacy and data protection risks (Billen *et al.*, 2015). Likewise, there are security concerns, for example terrorism and cyber-crime, around implementing 3D smart cities (Purkait & Das, 2018).

Section 2.6 Conclusion

This chapter presents the literature relevant to this study's research questions. Urbanisation and the drive for sustainable development within cities are highlighted as motivators for improved urban land management. A 3D multipurpose cadastre and LAS are presented as a possible solution to dealing with the new complexity in cities and the silos that exist through most LAS's. Finally, the uses of a 3D city model, the benefits seen and the challenges experienced are summarized.

Chapter 3 IDENTIFICATION OF THEORY AND SUITABLE METHODS

This chapter sets out the theoretical, methodological and analytical frameworks relevant to this study. It introduces and motivates for the use of land administration systems (LAS) theory, the mixed methods research (MMR) framework grounded in pragmatism, the single case study and in-depth interview methods, and systems thinking tools including soft systems methodology (SSM) and business process modelling (BPM). The selected research design was guided by the research objectives and aims.

Section 3.1 Land Administration Systems Theory

This section sets out the relevant LAS theory. There is a lack of diversity in LAS theory; much research has been published as practical guidelines rather than contributing to formal theory (Barry & Roux, 2012). Additionally, there are few established LAS definitions, because LAS are dynamic, highly complex and localized (Williamson *et al.*, 2010). The following theoretical concepts are inter-related and cannot be adopted separately from one another.

3.1.1 LAND, PROPERTY AND LAND ADMINISTRATION SYSTEMS

Land administration involves various functions within land management. Land management is "the process by which the resources of land are put into good effect" (UN/ECE, 1996) to achieve the goal of sustainable development (Enemark, 2006a; Williamson *et al.*, 2010). Land includes the natural and built environments, and therefore, all natural resources and improvements to the land (Enemark, 2006b) and is "legally classed as immoveable property" (Fisher & Whittal, 2020: 205). In this research, the term *property* is used interchangeably with *land*, as is common in geomatics industries. The relationship between land and people is managed by a LAS (Ibid.). LAS is a systems-based conceptual framework that creates the structure for executing land policy and management tactics (Williamson *et al.*, 2010).

The principal goal of a LAS is sustainable development through active public participation, informed decision-making and accountable governance aided by comprehensive, accessible, exchangeable, timely and valid property information (Williamson *et al.*, 2010; Aien *et al.*, 2013; Enemark, 2006a). An effective LAS supports the land administration functions of land tenure, use, development and value (see 2.2.4), as well as the management and protection of culturally significant and natural resources (Fisher & Whittal, 2020).

It is common, and appropriate, for LAS research to reference the notion of RRRs because it is an inclusive term that wholly captures the concept of property ownership (Fisher & Whittal, 2020). RRRs are "rights, restrictions, responsibilities in relation to property, land and natural resources" (Enemark, 2006a: 3). Rights are real and registerable rights in land and property, and are delivered and upheld by the land tenure function of the LAS (Williamson *et al.*, 2010). Restrictions are enforced upon the property by legislation to control and manage land use and development (Ibid.) and are prescribed by the land use and development functions of the LAS. Responsibilities are typically rooted in the social, cultural, or ethical environment and enforce a commitment on the right-holder to the rest of society and are typically set down by common law (Ibid.).

The RRRs held over the land parcel are managed and upheld by the cadastral system within the LAS (Bennett *et al.*, 2005). The four land administration functions deliver the RRRs and this should be achieved in a holistic manner to promote sustainable development (Williamson *et al.*, 2010). The RRRs concept supports the implementation of the sustainable development goals (SDGs)(Fisher & Whittal, 2020). However, sustainable development can only be achieved if RRRs are managed successfully in accordance with the GGPs (see 3.1.4)(Bennett *et al.*, 2005).

A Land Information System (LIS) that holds and integrates all information related to land[14] is necessary to uphold a well-functioning LAS (Fisher & Whittal, 2020). Furthermore, a successful LAS requires a spatial data infrastructure (SDI) framework that acts as a platform linking people and the LIS, enabling society spatially and a multipurpose cadastre (Williamson *et al.*, 2010; Jones & Land, 2012). As a platform, SDI enables the integration of many different types of property and geographic information datasets with the cadastre, and enables the movement of this data through different levels of government and society (Ibid.). The cadastre, containing land information and unique identifiers underpins the SDI and LAS (Williamson *et al.*, 2010).

3.1.2 THE CADASTRE AND CADASTRAL SYSTEM

The International Federation of Surveyors sets out the definition of a cadastre as follows:

> *"A Cadastre is normally a parcel-based and up-to-date land information system containing a record of interests in the land (e.g. rights, restriction and responsibilities). It usually includes a geometric description of land parcels linked to other records describing the nature of the interests, and often the value of the parcel and its improvements." (FIG, 1995: 1).*

A cadastre can be (i) juridical, capturing the legal interests in land; (ii) fiscal, for valuations and taxation purposes; or (iii) regulatory, in support of land use and development management (Fisher & Whittal, 2020). These align with the four land administration functions. Traditionally, the surface parcel, or erf, is the basic spatial unit of the cadastre (Stoter, 2004). It is the smallest unit that is capable of registration and it is a 2D entity. However, the RRRs tied to the erf are implied in 3D, extending in height and depth outwards from the surface (Fisher & Whittal, 2020). This is accepted as such by society as part of the paradigm that governs real property rights. This 3D implication of the RRRs attached to a land parcel defines the proprietary unit (Ibid.) or Legal Property Object (LPO)(see 1.1.2).

The cadastral system includes the cadastre and the persons, organisations, infrastructure, policies and procedures that are involved with achieving the land administration functions (Effenberg, 2001; Enemark, 2006a). The cadastral system's primary function is to capture the legal condition of land. The secondary functions of land use, development and value are achieved by making use of the relevant information extracted from the cadastral records in addition to other property records (Karki, 2013). Thus, the cadastral system supports the concept of a multipurpose cadastre (Jones & Land, 2012), the LAS and the implementation of the land management paradigm (LMP)(Williamson *et al.*, 2010).

3.1.3 THE LAND MANAGEMENT PARADIGM

The LMP supports land administration by providing the practices and values necessary to it (Williamson *et al.*, 2010). It is the "conceptual framework for understanding and innovation in LAS" (Ibid.: 7). The LMP is the foundation of land administration theory through which a country can achieve its land policy objectives (Ibid.). Land Policy forms a part of the national policies that promote national objectives (Enemark, 2006a) and is defined as "a complex of socio-economic and legal prescriptions that dictate how the land and benefits from the land are to be allocated, managed and administered" (Fisher & Whittal, 2020: 812). These objectives may include

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[14] See Fisher and Whittal (2020: 335) for a comprehensive list.

increasing tenure security, encouraging sustainable land use control and management, improving taxation of property, improving resource management and knowledge, and providing for minority groups and the disadvantaged (Enemark, 2006a).

The operative components of the LMP are the four land administration functions that support the implementation of the land policy objectives (Enemark, 2006a; Williamson *et al.*, 2010):

i. Land tenure, being the creation, maintenance and management of real property RRRs;
ii. Land value, encompassing property valuation and taxation;
iii. Land use, comprising of the management and planning of the use of land; and
iv. Land development, including management and planning of any urban and rural developments, construction works, infrastructure and utilities development.

These functions are administered by the LAS and the LMP approaches these functions holistically (Enemark, 2006a). Each function defines a subsystem of the LAS that can operate independently. However, they are inherently tied by a common feature, the erf or property right that is the subject of their function (Kalantari *et al.*, 2008). Thus, the functions are interrelated (Enemark, 2006a). Therefore, the LMP identifies the cadastral system as the foundation of any LAS (Williamson *et al.*, 2010).

Furthermore, the LMP supports the concept of a multipurpose cadastre and multidisciplinary LAS and, along with the rights, restrictions and responsibilities (RRRs) approach, "has the potential to include and make available the quantities of property-related information currently held in separate government departments and data repositories" (Fisher & Whittal, 2020: 339). The LMP supports the use of systems-thinking in LAS research and it associates the LAS with the RRRs and good governance principles (GGPs) (Williamson *et al.*, 2010; Whittal, 2014; Fisher & Whittal, 2020).

3.1.4 THE GOOD GOVERNANCE PRINCIPLES

Land governance concerns "the rules, processes and structures through which decisions are made about access to land and its use, the manner in which decisions are implemented and enforced, [and] the way that competing interests in land are managed" (Palmer *et al.*, 2009: 9). Governance is qualified as *good* if it conforms to the GGPs that reinforce and promote effective land administration (Williamson *et al.*, 2010; Whittal, 2011). The principles represent the ideal scenario that should guide land administration, rather than attainable objectives (Whittal, 2011). Hull and Whittal (2013: 345) summarise the GGPs, as applied to LAS, as "a) Efficient, effective and enduring; b) Transparency, accountability and the rule of law; c) Equity and participation; and d) Security and Integrity". The LAS should:

- Be accessible and affordable while taking into account data protection (Palmer *et al.*, 2009; Hull & Whittal, 2013),
- Hold accurate, up-to-date and comprehensive property information and promote tenure security (Wakker *et al.*, 2003),
- Take into account the cost versus benefits gained; be cost-effective (Williamson et al., 2010; Hull & Whittal, 2013; Coote et al., in press),
- Be transparent in processes, policies and procedures to empower the public (Palmer *et al.*, 2009; Whittal, 2011; Hull & Whittal, 2013),

- Be cognisant that improved ICT systems may exclude certain groups in a population, even as it increases efficiency (FIG, 1995),
- Be established in a sustainable manner with a long-term vision (Palmer *et al.*, 2009),
- Be driven by efficiency, effectiveness and equity (Whittal, 2011), and
- Be user-driven rather than purpose-driven (Enemark, 2006a).

3.1.5 THE MOTIVATION FOR LAS THEORY AS AN ANALYTICAL FRAMEWORK

Land administration theory, being globally accepted standards that are likely to "result in the optimum performance" of the LAS (Whittal, 2008: 88), was adopted here as the analytical framework. This included the land management paradigm (LMP), Spatial Data Infrastructure (SDI) and the principles of good governance (GGPs). Williamson *et al.* (2010) promote the LMP as a framework for investigating existing LAS. The LMP associates the LAS with the GGPs and the RRRs approach to work towards the holistic achievement of the land administration functions (Williamson *et al.*, 2010; Whittal, 2014; Fisher & Whittal, 2020). Whittal (2008, 2014) and Barry *et al.* (2012) advocate using the LMP in combination with a systems approach, as was adopted here. Additionally, Whittal (2008) used a combination of these methods successfully in modelling and analysing the CCT fiscal cadastral system. By adopting this approach, the important combination of social and technical aspects within land administration and management were accounted for (Barry & Roux, 2012).

Section 3.2 An Introduction to the Research Design

Research falls into one of three approaches: qualitative, quantitative or mixed methods (Johnson *et al.*, 2004, 2007). Each approach is grounded in a paradigm that influences the research process and knowledge production. The research approach and paradigm is important to discuss because they determine the author's process and results, and the manner in which the audience should approach the study. Qualitative and quantitative research and the associated paradigms are defined in *Appendix A*.

3.2.1 THE MIXED METHODS RESEARCH APPROACH

Phenomena are multi-layered and to gain the closest possible thing to truth, one should attempt to capture this complexity. MMR allows one to measure complexity by dynamically combining qualitative and quantitative approaches to achieve a holistic study of phenomena (Feilzer, 2010) and increase the depth and validity of the results (Maree *et al.*, 2007). If those results converge or are complementary, the confidence in those results is increased (Johnson *et al.*, 2007). It is the diverse nature of MMR that provides researchers with a methodology to answer complex problems in a more holistic manner.

A research paradigm is "a set of beliefs, values and assumptions that a community of researchers has in common regarding the nature and conduct of research" (Johnson *et al.*, 2007: 129). A paradigm acts as a window through which the researcher sees and analyses data, and through which the audience looks at the results; giving them a background to the researcher's process (O'Gorman & Macintosh, 2015). The complexity of MMR requires a flexible paradigm that is not prescriptive or exclusionary (Denscombe, 2008). However, this is not natural to paradigms (Feilzer, 2010). This is recognised as problematic in the field of MMR because the different methods that are combined, employ contradicting paradigms; leaving no comfortable fit for MMR (Denscombe, 2008; Feilzer, 2010; Denzin, 2012; Hall, 2012). However, MMR is focused on the practical combination of research approaches rather than a philosophical viewpoint (Morgan, 2014). Therefore, pragmatism is a recommended paradigm for MMR.

3.2.2 PRAGMATISM AS A RESEARCH PARADIGM

Pragmatism offers an alternative paradigm that pulls the research focus onto the aims of the research (Feilzer, 2010). It is associated with MMR because it supports the combination of varying data collection, processing an analysis methods (Feilzer, 2010). Pragmatism accepts the existence of both the scientific and the social world and that knowledge can be simultaneously constructed and based on reality (Johnson *et al.*, 2004). Truth and knowledge are viewed as inconstant and dependent on time and the environment (Ibid.). Pragmatism involves abductive reasoning, intersubjectivity and the transferability of knowledge (Johnson *et al.*, 2004; Morgan, 2007).

The adoption of pragmatism as a paradigm for MMR has been criticized, because it does not qualify as a paradigm per se. Pragmatism depends on the meaning of a phenomenon and that cannot be predetermined (Denzin, 2012). Pragmatism focuses on the results, using a retrospective process (Feilzer, 2010; Denzin, 2012). A pragmatist cannot discuss the choice of MMR or the methods selected until the study is concluded and therefore, pragmatism is unsuitable as a paradigm (Hall, 2012). However, Morgan (2014) discusses how pragmatism is both a practical approach and a paradigm, and bases his research on the work of Dewey (2008).

Pragmatism inherently involves making decisions on what aims are important and what methods will achieve those aims (Morgan, 2014). Pragmatism rejects the traditional top-down approach to research design that requires a chosen paradigm to be set down along with the researcher's ontology, epistemology and methodology (Morgan, 2007; O'Gorman *et al.*, 2015). Instead, pragmatism recognizes research as inseparable from human experience, in which the researcher's beliefs and actions that influence and inform the work in a circular knowledge creation process, become the focal point (Dewey (2008) cited in Morgan (2014)). These beliefs and actions create and inform each other in a circular process of knowledge creation (Ibid.). Therefore, pragmatism allows one to adopt different approaches within one study without having to ground the research in a chosen ontological and epistemological standing viewpoint (Morgan, 2014). Feilzer (2010: 8) states that pragmatism:

> *"sidesteps the contentious issues of truth and reality, accepts, philosophically, that there are singular and multiple realities that are open to empirical inquiry and orients itself toward solving practical problems in the 'real world'".*

It is thus through human experience that problem solving occurs.

3.2.3 CRITICISM OF MIXED METHODS RESEARCH

There is much criticism of MMR, mainly due to a lack of consistency among social scientists with regards to the field (Denscombe, 2008). MMR has no set definition, the debate on an appropriate paradigm is ongoing and the value of MMR has not been explicitly explained (Denzin, 2012). Social scientists disagree on whether, and how, quantitative and qualitative methods can be integrated, noting their incompatible paradigms (Denscombe, 2008).

However, successful MMR research provides evidence contradicting those criticisms (Denzin, 2012). MMR offers improved accuracy in the data collected and a more complete picture (Denscombe, 2008). Additionally, any inherent bias that would be present in a "single-method approach" is avoided by combining multiple methods (Ibid.:272). Furthermore, the adoption of MMR can offset the weaknesses of the variety of methods used and boost their strengths (Johnson *et al.*, 2004). Moreover, it is acknowledged that employing a rigorous approach to defining and directing MMR, aids in working within the pluralism inherent to this methodology (Creswell & Plano Clark, 2011; Plano Clark & Ivankova, 2016).

3.2.4 MOTIVATION FOR THE ADOPTION OF MMR GROUNDED IN PRAGMATISM

This research adopted an MMR approach grounded in pragmatism. MMR is a recommended approach for LAS research as it accounts for the inherent duality and complexity present in this research type (Whittal, 2008; Feilzer, 2010). Furthermore, it allows for the integration of different data collection and analytical methods, increasing a study's depth and reliability. Both Whittal (2008) and Karki (2013) successfully employed a MMR approach to LAS analysis. To successfully model the current state of the CCT Property Management System (PMS), both the social and the technical aspects of the LAS needed to be analysed. This indicated that a MMR approach would be the best-suited to this research. By adopting MMR, the researcher was able to combine various data sources and analytical tools that supported examining the LAS from various angles. Furthermore, by allowing a suitable combination of methods to be applied, flexibility was introduced, promoting creativity and a more holistic outlook on the system-in-focus.

Similarly, pragmatism as a paradigm allows one to select tools from a variety of disciplines that can practically achieve the research aims while avoiding lengthy arguments about philosophical standings. Therefore, the researcher, in adopting pragmatism, was able to practically combine different methods of data collection and analysis to allow for the holistic study of the CCT PMS as required to answer the first research question. Furthermore, the potential use and benefits of 3D were investigated from both a technical and a social viewpoint, to gain a broader understanding of the possibilities at hand. This reinforces the adoption of MMR grounded in pragmatism.

Section 3.3 A Mixed Methods Research Framework

Appropriate methods should be selected and combined in MMR according to their capability to aid in realising the study objectives. The method statement should set out the study design, sampling strategy, qualitative and quantitative data types, collection and data analysis methods, and data and method integration (Plano Clark & Ivankova, 2016).

3.3.1 THE CASE STUDY STRATEGY

Yin (2003: 13) defines a case study as

"an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between the phenomenon and context are not clearly evident."

The case study allows one to produce an all-inclusive, meaningful analysis of real life situations, events, processes and the dynamics present, by combining qualitative and quantitative approaches (Eisenhardt, 1989; Yin, 2003). Quantitative data uncovers the relationships between variables, but qualitative data provides an explanation for these relationships (Ibid.). Therefore, case study research is well-positioned to accomplish both within a MMR strategy. Case studies support the examination of social organisation and the typical patterns that can be identified within it (Seale, 2004). Barry and Roux (2012) recommend the case study method (see 3.3.1) for LAS research because one can include and combine any data, whether qualitative or quantitative, deemed relevant to the study. The case study is good for the *how* and *why* research questions, because one can look into the context of the phenomenon (Yin, 2003).

Case studies can take the form of either a single- or multiple-case study design (Eisenhardt, 1989; Yin, 2003). Multiple-case study research observes similar cases under different circumstances, while single-case research observes only one case (Ibid.). Single-case study design is suited to investigating an "extreme or unique case", or a "representative or typical case" (Yin, 2003: 40). It does not build theory but can be used to test existing theory (Ibid.). The objective is to conduct an in-depth investigation of a specific case to gain a richer understanding of that case, thereby contributing to the knowledge of that case. Although generalization is not typically the aim of a single-case study, it may be used for naturalistic generalization (Ibid.). A single-case study was successfully employed to analyse unique cadastral systems by Barry *et al.* (2002) and Whittal (2008).

i THE SUITABILITY OF A SINGLE CASE STUDY DESIGN

In this research, a single-case study method was employed to describe, analyse and model the system-in-focus: the CCT Property Management System (PMS). The CCT PMS was identified as a unique system and therefore a single-case study was deemed appropriate. It is unique compared to other subsystems within the SA LAS because each municipality in SA creates their own PMS that is subject to local municipal legislation, as well as the national legislation (see 1.1.1). The CCT PMS is a subsystem of the greater LAS and cannot be analysed separately from its environment, thus making the case study method ideally suited for this research. Furthermore, the modelling of the PMS had to recognize both the technical and social aspects of that system which are accounted for using a case study. Case studies allow for the inclusion of "social, management and operational elements" in a single research project which is necessary in LAS research (Barry & Roux, 2012: 10). Additionally, the model and description of the CCT PMS has not been attempted before and therefore this research was exploratory. Case studies are recommended for early stages of research and for testing hypotheses (see 3.3.1)(Eisenhardt, 1989). Furthermore, Whittal (2008) successfully employed the single-case study method in modelling the CCT fiscal cadastral system. Therefore, this method was judged suitable for this study's purposes.

ii A CRITIQUE OF THE CASE STUDY

Case study research is critiqued as being only appropriate in exploratory phases and therefore only applicable to describe or test hypotheses (Yin, 2003). Additionally, there is criticism that case studies are open to bias, are laborious and difficult to conduct, are inaccessible to the audience and are inadequate for scientific generalisation (Neuman, 2000; Yin, 2003; Whittal, 2008). However, case study analyses preserve the whole and significant characteristics of reality (Yin, 2003). This method deals with a full variety of evidence and builds a rich data set, and therefore it can be used to build or test theory or describe events (Ibid.). Case studies are particularly useful in the early stages of research (Eisenhardt, 1989). Furthermore, most critique can be combated using triangulation; enabling a convergence of evidence to strengthen the validity and reliability of the results (Yin, 2003). Moreover, any bias evident can be minimised by employing a rigorous research design that declares any possible bias upfront (Whittal, 2008).

iii CASE STUDY DATA SOURCES

Case studies combine data collection sources such as interviews, documents, and observations (Eisenhardt, 1989; Yin, 2003). Each data source makes a contribution to the study's holism (Baxter & Jack, 2008). The integration of the different sources is aided by the creation of a case study database that is used as a tool to maintain the sequence of evidence (Yin, 2003).

Documentation evidence are valuable in constructing cases and include correspondence, protocols, policies, legislation, standards, reports, press extracts, organisation charts and organograms, agendas, meeting minutes, plans and maps (Yin, 2003). Documentation necessarily includes digital information; websites, presentations and GIS hold much data, especially in a LAS context. Additionally, visual and audio data are important sources of evidence in case studies (Pelto & Pelto, 1978). These sources should not be assumed to be free from bias and should not be assumed to be an objective record (Yin, 2003). Bias may be uncovered with data triangulation and avoiding an over-reliance on these data types (Ibid.). Accessing documentation data may be difficult, because of privacy or security concerns (Ibid.).

There are two types of observation evidence: direct or participant (Yin, 2003). Direct observations involve the researcher making a visit to the site of the case study. Participant observation involves the researcher playing an active role in the case being investigated (Ibid.). If the researcher has personal experience of a case, he or she can be a valuable information source (Pelto & Pelto, 1978). This should be approached with care however, because the researcher's perspectives on the topic may influence their experience and record thereof (Ibid.), leaving room for potential bias (Yin, 2003). Finally, the interview is one of the most important sources of case study data (Ibid.). Typically, interviews used for case study data collection are unstructured or semi-structured allowing for fluidity of conversation (Ibid.).

3.3.2 THE IN-DEPTH INTERVIEW METHOD

Boyce *et al.* (2006: 3) define in-depth interviewing as

> *"a qualitative research technique that involves conducting intensive individual interviews with a small number of respondents to explore their perspectives on a particular idea, program, or situation".*

In-depth interviews are an appropriate data collection method if the research questions require "accessing an individual's personal experience, understandings and perceptions" (Morris, 2015: 13).

i SEMI-STRUCTURED IN-DEPTH INTERVIEWS

A semi-structured in-depth interview sets out structured questions that act as a conversation guide, but allow for unplanned questions to be added as the dialogue flows (Dicicco-Bloom & Crabtree, 2006; Morris, 2015). This allows the respondent freedom to express certain views that may be of interest and that may otherwise not be revealed in a more structured environment (Neuman, 2000; Dicicco-Bloom & Crabtree, 2006; Morris, 2015). This is valuable to case study data collection, because although one maintains the desired focus by following the structured questions, there is room for fluidity in conversation to uncover new information (Yin, 2003). However, it is important that the interviewer avoids veering off subject by maintaining focus on the research questions (Morris, 2015). This can be achieved by developing a rigorous interview guide[15], developed directly from the research questions, that provides a semi-structured process (Ibid.). Furthermore, the interviewer should ask questions that are unbiased and non-threatening (Yin, 2003). The respondent should be encouraged to share as much information as possible, without using leading questions or comments that may influence the respondent's answers (Dicicco-Bloom & Crabtree, 2006).

An interviewee is identified in the study by their specific knowledge and their role within a situation or organisation (Dicicco-Bloom & Crabtree, 2006). An individual may be highlighted by a case study (through

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[15] See *Appendix B* for the interview schedule.

involvement) or may be referred to by another interviewee. This leads to a snowball effect of expanding the network of interviewees until no new information is gained through the interviews. An interviewee is a 'respondent' until such a time as they respond to such an extent that they become an 'informant' (Yin, 2003). A key informant not only provides information on a case of interest, but offers additional data sources. This yields a greater depth of information and understanding. However, Yin (2003) warns of becoming over-reliant on a few key-informants, as this may introduce unwanted bias.

ii CRITICISM OF IN-DEPTH INTERVIEWS

The advantage of employing in-depth interviews is that the data collected is rich and varied. However, this can result in laborious and expensive analyses (Boyce & Neale, 2006). Another disadvantage is that the respondent may give subjective, dishonest or incomplete answers and these are difficult to identify (Morris, 2015; Julin *et al.*, 2018). Additionally, the data is not generalizable to the population, because of the small sample sizes and the risk that the interview may be biased (Boyce & Neale, 2006; Morris, 2015). These limitations can be minimized by employing data triangulation to combine the interview data with other information sources (Morris, 2015). Additionally, adopting a reflexive attitude can increase the interview data validity (Ibid.).

iii THE SUITABILITY OF IN-DEPTH INTERVIEWS

Semi-structured in-depth interviewing was employed in the process of data collection, because this is an exploratory study into the CCT PMS and the potential need for 3D within that system. Therefore, the outcomes could not be predicted. In-depth interviewing is well-suited to exploratory research (Dicicco-Bloom & Crabtree, 2006). Furthermore, semi-structured interviewing was selected over unstructured interviewing because, as an inexperienced interviewer, there was a risk of the interview running off-course. Land administration and 3D city models are broad fields of enquiry and the technical details can be complex. Therefore, branching off into unrelated topics is easy and directing the interview was necessary. An interview guide was created and used to guide conversation (see *Appendix B*). Thus, the in-depth interview method is adopted in a pragmatic manner.

3.3.3 THE ANALYTICAL FRAMEWORK

Following data collection, analysis is undertaken to extract patterns and meaning to draw conclusions. However, in a case study, data collection and analysis can happen concurrently and inform one another (Neuman, 2000; Yin, 2003). There are various analysis tools that can be employed to increase the validity and reliability of the evidence and the conclusions (Yin, 2003; Johnson *et al.*, 2007; Feilzer, 2010; Denzin, 2012).

i RELIABILITY AND GENERALIZABILITY

A research strategy's quality can be judged using logic tests, including reliability and generalizability (Yin, 2003). Reliability of the findings is a measure of whether the same study could be repeated using the same process and result in the same conclusions. This shows that the operations used in the research are reliable and minimises the effects of bias (Ibid.). Generalizability is the transferability of the results from the specific research context to the broader context (Tashakkori & Teddlie, 2003; Onwuegbuzie & Leech, 2006). MMR and the use of single-case studies rely on naturalistic generalisation (Yin, 2003). Naturalistic generalisation analyses a particular case, relying on the case narrative to gain an understanding of the results and judge whether those results can be generalised to other similar cases (Ibid.). In-depth interview data is not typically generalizable (Boyce & Neale, 2006), but triangulation can increase generalizability.

ii TRIANGULATION IN MMR

It is important to employ triangulation in MMR to encourage inventive data collection techniques and theory combinations, increasing the depth of a study (Yin, 2003; Johnson *et al.*, 2007; Denzin, 2012). Furthermore, it can uncover research biases and inconsistencies, providing increased confidence in the results (Johnson *et al.*, 2007; Denzin, 2012). Importantly, triangulation develops a convergence in the lines of inquiry; if a combination of different triangulation types result in the same conclusions, this is a convergence of evidence and the conclusions are corroborated (Yin, 2003) . Additionally, this indicates successful triangulation (Ibid.). There are four types of triangulation (Denzin, 2012):

- Data triangulation (combining a variety of data sources),
- Investigator triangulation (using a number and variety of researchers),
- Theory triangulation (making use of a variety of theories), and
- Methodological triangulation (combining multiple methods).

It must be noted that using the triangulation of multiple sources of evidence is challenging to the inexperienced researcher, because it requires a familiarity with multiple techniques and it can be resource-hungry (Yin, 2003).

MMR supports the use of triangulation by allowing for the pragmatic combination of different methods, sources, and theories. Triangulation of different methods and data sources was adopted in this study to increase the rigour, trustworthiness and richness of the research (Johnson *et al.*, 2007; Denzin, 2012). Whittal (2008) used this methodology successfully for analysing LAS. By adopting various forms of triangulation in the data analysis, the validity and depth of the study was increased.

iii CASE STUDY TOOLS

A "chain of evidence" increases the reliability of the results and the construct validity of the case study (Yin, 2003: 105). The evidence chain allows the reader to follow the researcher's path of establishing the research questions, to data collection and organisation, extraction of information, and analysis of the results. The chain should be unbroken, in other words, no original data should be missing (Ibid.). The study's reliability is improved by the accessibility of the original data and the clarity of the path followed by the investigator (Ibid.). The original, collected data on which the case study findings are based, are held in a case study database that assists with building the evidence chain and increasing reliability (Ibid.). This allows others to review the data directly, along with the findings, corroborating the conclusions drawn (Ibid.). A detailed case study report should be drawn up to aid within-case analysis (Eisenhardt, 1989). Within-case analysis aids in building the case study database and allows the investigator to gain familiarity with the data and to identify patterns within the case (Ibid.).

iv SYSTEMS-THINKING TOOLS

Systems-thinking, and the various tools it encompasses, best support the understanding and analysis of systems. This approach is set out in Section 3.4. It supports the modelling of the current and ideal states of a system and its nature and elements, subsystems, functions, interactions and environment. Additionally, Business Process Modelling (BPM)(see3.4.2) is a framework that supports the investigation of the processes within an organisation, offering a different perspective on a system.

3.3.4 THE RESEARCH CONTEXT: BIAS AND ETHICS IN MMR

A researcher's personal, interpersonal and social contexts influence their decision-making and attitude to MMR (Plano Clark & Ivankova, 2016) resulting in possible biases that must be acknowledged. A researcher's personal philosophies, their ingrained ideas on what constitutes reality and knowledge, and what research entails, can affect the research design (Ibid.). Additionally, a researcher's background, their experiences and knowledge held from current or previous work or study, shape how they approach research (Ibid.). Furthermore, an investigator may be prone to weighting information collected more heavily if it is deemed to be better defined or less complex than other data, sourced from a person of high status or consistent with the researcher's anticipated findings(Eisenhardt, 1989).

A researcher's interpersonal context includes their ethics and their relationship to the study participants (Plano Clark & Ivankova, 2016). Ethics are a set of *moral principles* that guide the researcher in conducting ethical research with an emphasis on protecting human subjects (Ibid.). The researcher must make an appropriate ethics application to the relevant ethics board with regards to the proposed study (Ibid.). Additionally, the participants must be informed on the specifics of the research process and the publishing details (Ibid.). Informed consent must be sought from each participant prior to their participation (Ibid.).

Rigorous research design and the use of triangulation assists in reducing or eliminating any possible bias to aid the research process (Whittal, 2008). Additionally, the use of expert key informants from different backgrounds as data sources is recommended to gain a variety of perspectives and knowledge, thereby combating the risk of researcher bias (Ibid.).

Section 3.4 Systems-Thinking Approaches

Systems-thinking approaches support "holistic analyses" of the social and technical elements of a system, and the "non-static land management sub-systems" from different perspectives and are recommended for LAS analysis (Barry & Fourie, 2002: 23). A system is defined as an "entity made up of interacting parts operating in an environment" (Leonard & Beer, 1994: 4) to achieve a common goal (Checkland, 1999). It is an irreducible whole with a definable boundary that consists of internal and external components and input and output processes (Checkland, 1999; Mele *et al.*, 2010). Thus, systems-thinking enables a holistic understanding of a system and its functions within its context (Whitten & Bentley, 2007; Mele, *et al.*, 2010; Çağdaş & Stubkjær, 2011). It allows for a broad view of a real-world problem within set boundaries (Leonard & Beer, 1994; Checkland, 1999). The research objectives define the boundaries of the system to be modelled and aid in selecting the modelling tools (Leonard & Beer, 1994; Aguilar-Savén, 2003). It is essential the system-in-focus is correctly defined to answer those research objectives (Leonard & Beer, 1994; Whittal, 2008). This includes the system that is the subject of examination and analysis (Beer, 1995), and its external environment (Whitten & Bentley, 2007). The boundaries are the interface between the system and its environment (Checkland, 1999).

Systems' thinking adopts a holistic approach, meaning the whole is seen as being made up of a number of sub-systems and itself forms part of a greater system (Checkland, 1999). The whole is more than the sum of its parts, and each part contributes to achieving the shared aims (Checkland, 1999; Barry & Fourie, 2002; Jackson, 2003). The individual parts may be examined individually (Checkland, 1999; Barry & Fourie, 2002; Çağdaş & Stubkjær, 2011). Furthermore, systems are recursive in nature, each level in a system contains all the levels found below it (Beer, 1995). Typically, the relationships and functions recur at each level throughout the system (Leonard & Beer, 1994). Furthermore, no system acts in isolation and the relationships and interactions of the system-in-focus with the environment should be investigated (Barry & Fourie, 2002; Whitten & Bentley, 2007). The environment includes external agents that interact with the system-in-focus (Whitten & Bentley, 2007).

A system model is a representation and simplification of reality to facilitate analysis (Checkland, 1999). The model of the system and its boundaries is capable of adjustment as the researcher's understanding develops (Leonard & Beer, 1994). The model should go through testing to show if it adequately predicts the system's behaviour (Ibid.). Finally, the model should be revised and redefined. A number of different models of the system-in-focus and sub-systems may be necessary before one can fully understand the relationships (Barry & Fourie, 2002). The model that is best suited to the investigation is then adopted for analysis. It is important to note that the investigator defines the system from their specific context and with the tools they have selected (Leonard & Beer, 1994; Barry & Fourie, 2002; Aguilar-Savén, 2003; Mele *et al.*, 2010). Thus, there is inherent subjectivity involved that can change how a system is modelled.

Systems-thinking tools are recommended in LAS research (Barry & Fourie, 2002) and were adopted here to facilitate and strengthen the understanding and model of the system-in-focus. The pragmatic MMR approach advocates for the selection of tools that aid in the achievement of the research objectives. Thus, certain systems-thinking tools are made use of in this study that are appropriate to the research questions, while others are discarded as inappropriate for meeting the research aims. By adopting some systems-thinking tools into the case study analysis, triangulation was employed to increase the confidence in the results and reduce the potential for bias. There are several different systems perspectives that have developed over the years to facilitate the modelling and analysis of systems. Soft Systems Methodology (SSM) and Business Process Modelling (BPM) are relevant to this research.

3.4.1 SOFT SYSTEMS METHODOLOGY

SSM was developed by Checkland (1981, 1999) and can be defined as a "process-orientated approach for channelling debate about situations characterized by messy ill-structured problems with multiple perspectives" (Leonard & Beer, 1994: 32). Hard systems methodology struggles to cope with complex human activity, diverse points of view and unstructured problems or aims. Therefore, SSM was designed to gain a holistic understanding of a system within its environment without excluding social complexities (Checkland, 1981, 1999). Furthermore, SSM is recommended to better understand LAS because it avoids oversimplification by allowing for complexity within the model (Barry & Fourie, 2002).

SSM comprises of a range of tools that can be *pragmatically* applied as necessary in a study. There are seven stages in SSM (Checkland, 1981, 1999) and these are presented in Leonard *et al.* (1994) and Burge (2015). Stages i) and ii) deal with an analysis of the current real-world system and identifying the problem:

i. Investigate the problem (gather information on the existing problem and system)
ii. Structure the problem (gain an understanding of the current state of the system-in-focus)

Stages iii) and iv) are concerned with the ideal system. Stages v) to vii) present the action necessary to bring about change (Leonard & Beer, 1994). SSM stages i) and ii) are pragmatically employed in this study and these stages make use the rich picture tool (Checkland, 1999).

The rich picture is useful to unpack complex real-world systems, processes and relationships through the use of multiple creative drawings depicted from various perspectives (Aguilar-Savén, 2003; Burge, 2015; Bell *et al.*, 2019). This process highlights themes within the system-in-focus and an understanding is gained more readily and effectively through the use of pictorial representations than the use of words (Checkland, 1999; Burge, 2015). Therefore, rich pictures provide an efficient route to a deeper understanding of the complex system-in-focus.

There are no formal modelling rules for rich pictures and this can result in ambiguity (Aguilar-Savén, 2003). However, some standards have been developed to combat this (Burge, 2015). Additionally, the flexibility of this tool is important to allow for the effective visual communication of a complex real-world situation that is not limited by strict notation rules and therefore allows for creativity (Ibid.). Moreover, SSM should be combined with other complementary models[16] to provide increased validity in the findings (Leonard & Beer, 1994; Jackson, 2003). BPM is a complementary tool that may be used.

3.4.2 BUSINESS PROCESS MODELLING

A system consists not only of its structure, components and relationships, but also the processes that occur within it and with its environment (Checkland, 1999). A business process is "the combination of a set of activities within an enterprise with a structure describing their logical order and dependence whose objective is to produce a desired result" (Aguilar-Savén, 2003: 129). BPM supports the description, understanding and improvement of business processes (Mendling *et al.*, 2010), in particular, existing business processes (Aguilar-Savén, 2003). There are many BPM tools, therefore the research objectives should guide the tools selection (Ibid.). The data flow diagram (DFD) is suitable for projects that aim to define complex and detailed business processes for learning purposes without the aim to implement changes (Aguilar-Savén, 2003; Kolhatkar, 2011). It is easier to learn than other BPM tools (Godwin *et al.*, 1989) and is therefore, ideal for use by a novice in systems-thinking tools.

A DFD is a graphical representation of the "flow of data or information from one place to another" (Aguilar-Savén, 2003: 134) and the work done by that system (Whitten & Bentley, 2007). The processes are defined by the data flows between data stores, and their relationship to the users and environment (Aguilar-Savén, 2003). DFDs are flexible, easy to create, interpret and verify, and can show main and sub-processes (Aguilar-Savén, 2003; Whitten & Bentley, 2007). To model a process, a researcher will need to identify the sub-processes and subsystems using decomposition diagrams; a necessary planning tool for DFDs to increase understanding (Whitten & Bentley, 2007).

The flexibility of DFDs can be a disadvantage, because the process boundaries may not be clearly defined (Aguilar-Savén, 2003). This can result in the chart becoming overly large, complicated and therefore, difficult to read; it can be challenging to distinguish sub-processes from the primary processes (Ibid.). Furthermore, the modelling process is time-consuming (Kolhatkar, 2011). However, the DFD tool includes set notation standards that increase the structure and efficiency of the modelling process (Aguilar-Savén, 2003).

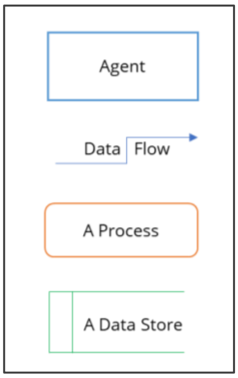

Figure 3-1: DFD Gane & Sarson Notation

Multiple notation standards are seen employed in DFDs by different researchers (Kolhatkar, 2011). The Gane and Sarson notation (see Figure 3-1) is recommended and includes set terminology (Whitten & Bentley, 2007). A *data flow* is "data in motion"; either an input into or an output from a process (Ibid: 320). It is a communication between two processes or between a process and the environment (Ibid.). A *data store* is "data at rest"; effectively holding data for use by the system at a later stage (Ibid.: 320). A *process* is a transformation; it is action taken in reaction to input data flows

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[16] Whittal (2008) successfully uses SSM in combination with Hard Systems Methodology and Viable Systems Modelling.

(Ibid.). An *agent* interacts with the system and they either produce or consume data (Whitten & Bentley, 2007; Kolhatkar, 2011).

As stated above, a system consists of structures as well as processes and it is necessary to understand the relevant processes that affect the PMO to gain the required understanding of the PMS. Therefore, techniques of BPM are a useful addition to those tools already identified. The CCT PMS was modelled using BPM DFDs and the Gane and Sarson notation, as this method is recommended for modelling a system based on its data flows (see 3.4.2). Furthermore, DFDs are recommended as an investigative tool best used to describe a system, rather than be used to implement changes (Aguilar-Savén, 2003; Kolhatkar, 2011). Therefore, the use of DFDs is appropriate for achieving the objectives of this study. Moreover, DFDs are easy to interpret and allow for increased understanding of complex systems, such as a LAS.

Section 3.5 Conclusion

This chapter has set out the theory and methods applicable to this study. The concepts are set out comprehensively to ensure a strong foundation to the research and their use is motivated. The tools and theory adopted in this study include mixed methodology grounded in pragmatism, single case study and in-depth interview methods, various analytical tools including a chain of evidence, within-case analysis, SSM and BMP, as well as the LMP, GGP, RRRs and SDI. Based on the frameworks presented, the investigation and analysis of the CCT PMS with respect to the management of property in 3D is facilitated.

Chapter 4 THE RESEARCH DESIGN

This chapter sets out how the adopted methodological and analytical frameworks were employed within this study's research design. The objectives of the study were achieved by combining a different data collection and analysis tools in a MMR framework. The primary method adopted for the methodological framework was the single case study featuring a complement of case study and systems approach tools. The systems approach was adopted pragmatically and made use of methods from both SSM and BPM (see Section 3.4, 4.3.2), namely; rich pictures and data flow diagrams. Additional tools were adopted from the case study method, including in-depth interviewing, a case study database, triangulation, within-case analysis and a chain of evidence. Finally, best practices in land administration theory were adopted as the analytical framework and foundation to the study (see 3.1.5).

The combination of systems-thinking and case study tools was promoted by Whittal (2008) for LAS research because it increases the results construct validity and encourages a broader understanding of the system. This research aligns with that methodology with the addition of in-depth interviews as a rich data source. This study employs the simultaneous use of qualitative and quantitative data collection and analysis. This is in-line with a pragmatic approach that employs continuous abductive reasoning (Feilzer, 2010), moving constantly between the research stages as insights are gained. Therefore, the in-depth interviews were conducted simultaneously to the data processing, allowing the researcher time to sift through data collected and identify new areas to investigate.

Section 4.1 The Use of the Single Case Study Method

In this research, the system-in-focus, the CCT Property Management System (PMS), was described, analysed and modelled using a single-case study method to aid answering both the research questions (see Section 1.3). The single-case study was deemed appropriate because the CCT PMS was identified as a unique system. Each SA municipality creates and manages their own PMS within the greater SA LAS, even while it is subject to national, provincial and local municipal legislation (see 1.1.1). Therefore, the CCT PMS is a unique subsystem of the LAS and can be analysed as such.

Section 4.2 The Case Study Data Sources Employed

There are various possible sources of case study data (see 3.3.1iii). The data sources adopted included documents, visual data, direct and participant observations, and semi-structured in-depth interviews. These were combined and used in an iterative and retrospective manner, aligned with the MMR approach. Data was collected over the period 2018-2019 and most of the interviews were conducted in 2018. This allowed sufficient time to conduct data collection, process the data and identify new sources of data for further investigation. Thus, the data collection process was refined over two years and a level of saturation was reached indicating that the process was successful (Yin, 2003).

4.2.1 THE USE OF DOCUMENTS AND VISUAL DATA

The documentary sources played a significant role in investigating the case study, the CCT PMS, presented in Chapter 5. To fulfil the first research objective of creating an accurate model of the PMS, official documentation was favoured over in-depth interview data. This approach was to avoid issues of hearsay and rather rely on documented processes or organizational structures. However, to avoid bias, data triangulation was employed by combining the documentation evidence with interview and observation data. The documentation used for the modelling of the CCT PMS included CCT protocols and policies; relevant national and municipal legislation; organisation records, charts and organograms; webpages; presentations; reports, minutes, press extracts, correspondence and memoranda.

The second research objective of presenting the current use and potential need for 3D (see Chapter 6) involved some documentary evidence. The examples of how 3D is currently used in the CCT was supported by documentation and visual data. Major data sources were existing GIS projects, 3D models, pdfs and animations that have been produced for CCT use. Furthermore, maps, plans, the CCT Development Management Scheme (DMS) regulations (2015) and survey records were used to further support the current examples of 3D. Additionally, there has been movement towards investigating the uses of 3D and this is documented in presentations, meeting minutes and correspondence, to which the researcher was privy to.

It must be noted that the majority of documentation evidence was gained via the interviewees, whether directly or via referral. A lesser amount of documentation evidence was gained through the author's work experience at the CCT and as a land surveyor, or by conducting investigations online. Documentation was loaded into the case study database, see 3.3.3iii, assigned a reference number and referenced as necessary in the following chapters.

4.2.2 DIRECT AND PARTICIPANT OBSERVATION

The data collection included both participant and direct observation as defined by Yin (2003)(see 3.3.1iii). Initially, the researcher was employed at the Surveyor General's Office as a land surveyor. At this point in time, being 2016 and 2017, the researcher built a relationship with the CCT Geospatial division and used those contacts for the initial interviews. Those initial respondents led to references to new interviewees within other departments. Thus a snowball-sampling approach was used. Additionally, that relationship allowed the researcher to directly observe 3D use cases that the Geospatial team were working on.

Since mid-2018 the researcher has been employed in the CCT Geospatial division which forms part of the single-case study, the CCT PMS. Therefore, she was a participant observer in the system-in-focus. The position the researcher was employed to was beneficial to this research, because she consulted, as a Professional Geomatics Officer, with all the departments that form the CCT PMS, including Planning & Building Development Management (PBDM) and Valuations. The consultation role included working on geospatial solutions for internal departmental problems. This gave the researcher a more in-depth view into each of these departments, their inner workings and of the PMS as a whole. More so than could be gained from looking in from the outside.

Furthermore, it can be said that each department, being focused on their own goals, does not understand the functioning of the other departments. The researcher could move across these boundaries and learn about each departments' role in the PMS and how it functioned. This was direct observation data collection. The researcher additionally has a working relationship with the IS&T and Corporate GIS departments and this allowed for much needed insight into the technical systems that support the CCT PMS. Part of this understanding was gained through direct and participant observation, and part from the in-depth interviews and documentation.

Her position necessarily allowed the author easier access to internal documentation resources and to identify potential interviewees. (Although 90% of the interviews were conducted prior to the researcher's employment by the CCT.) The researchers position at the CCT allowed for considerable experience, both as a participant and direct observer, in 3D use cases and research into the future implementation of 3D. For example, the author often sits in on meetings as an expert in geospatial data where the need for 3D is discussed. As a result of this, a research group was formed that the author is part of, that focused on looking at the potential and need for implementing a 3D Smart City[17] solution at the CCT. This is participant data collection as the researcher was a part of the process.

It must be noted that the high level of researcher participation in the system-in-focus could introduce a high risk of bias, at the same time as adding rich detail to the data collected. The risk of bias is reduced by using a rigorous research design and triangulation of data sources and collection and analysis methods. The potential for bias in this data collection technique is dealt with in Section 4.4.

4.2.3 THE USE OF IN-DEPTH INTERVIEWS

The case study data collection includes semi-structured in-depth interviews (see 3.3.2i) with a wide-range of CCT officials from a variety of departments to gain insight into the case study, the CCT PMS. The first half of each interview was structured to collect data and maintain focus on the PMS. The second half was focused on the respondent's experiences with and opinion on 3D property information and city models. The Interview Guide sets out the core structure of each interview while allowing conversation to flow freely (see *Appendix B*).

Firstly, the interviews held were used to gain insight on the structure and processes of the system-in-focus. It was important to understand how property information flows within each PMS subsystem and how the subsystems and environment interact. This allowed the researcher to construct a model of the CCT PMS focused on the use and management of property data. The interview data was integrated into the case study and corroborated with the other data sources (see 4.2.1, 4.2.2) to strengthen the analysis (see Section 4.3). Secondly, the interviews aimed to uncover and understand the current uses of 3D in the PMS and any disadvantages of not having 3D. This was followed by the foreseen challenges of representing the third dimension and what potential benefits the interviewees envision 3D bringing to the CCT.

To answer the second research objective of the current use of, and potential need for, 3D in the CCT PMS, the in-depth interview data was relied upon more heavily than the documentation. This is due to 3D being in its fledgling stages in the CCT and there being a consequent lack of documentation or other evidence to support the interview data collected. All available documentation was incorporated with participant and direct observation to increase data source triangulation. This was viewed as acceptable because the researcher aimed to answer whether 3D is in fact necessary, before a 3D solution is introduced, and therefore it can be expected that there would be insufficient documentary evidence available.

i IDENTIFYING THE RESPONDENTS

Initially the agencies that play an obvious role in the CCT PMS were identified. This was achieved by identifying agencies that fulfil the land administration functions of land use, development and value. This step involved systems-thinking (see Section 3.4) to develop an understanding of the systems at play within the PMS and the relationship the system-in-focus has with its environment. This led to the identification of the initial key role players for interviewing (see 4.3.2i).

The in-depth interviews were conducted with carefully selected individuals identified to have an interest in or work in a field that would be pertinent to achieving the land administration functions and/or to introducing 3D

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[17] See *Appendix A*.

into the LAS. The interviewees were identified on a referral basis, using a snowball-sampling strategy (see 3.3.2i). Furthermore, the researcher was able to identify potential interviewees once she had taken up the post at the CCT. The snowball-sampling strategy was seen as successful because, at a point, the interviewees ran out of new potential responders, and the process reached saturation. In total, 38 interviews were conducted with respondents from a variety of backgrounds and ranks including professional land surveyors, town planners, development management officials, Geomaticians, IT specialists, valuations officials, property managers, built environment academics, and CCT managers from various departments. Over 75% of the interviewees were CCT employees, as expected due to the CCT PMS being the focus of this research.

ii INFORMED CONSENT AND CONFIDENTIALITY

Informed consent was acquired from each participant as per the Faculty of Engineering and Build Environment ethics code (University of Cape Town, 2010). The participants could request full anonymity. However, their contact details were kept for correspondence purposes. Each interviewee is assigned a pseudonym in the form of an interview code (for example, I01) and this was used for data storage, processing and reporting to ensure confidentiality. These codes are used for referencing in the following chapters. A research request, including permission to conduct interviews, was granted by the CCT (see *Appendix E*). Additionally, the CCT pre-approved the final thesis.

iii THE INTERVIEW PROCESS AND DEVELOPING THE INTERVIEW GUIDE

The initial interviews took place sporadically in 2016 and 2017 as the author was establishing the research topic. These initial interviews and the research questions were used to develop and shape the interview guide. The interview guide was created and used to direct conversation flow (see *Appendix B*).

The interview guide does include a high level of detail to assist the unexperienced interviewer to keep focus on the research aims, but it must be noted that the interview guide was not prescriptive. The interviews held were fluid and allowed to progress in a natural manner, following a semi-structured approach. Thus, the interviewer referred to the guide intermittently through the interview to confirm that all relevant topics had been discussed in one way or another. In other words, the guide was used principally to direct the interviewer rather than the interviewee. Furthermore, not all interviewees would or could answer all the questions listed in the guide, and therefore were allowed to deviate from the guide as necessary. The guide attempted to cover all possible relevant topics due to the exploratory nature of this research. Those interviewed at the initial stage were re-interviewed in 2018 using the semi-structured interview guide for continuity's sake. The majority of the in-depth interviews were held in the months of April to June 2018 prior to the researchers' employment at the CCT.

Each participant was interviewed individually, using the interview guide (see *Appendix B*) that contains guiding questions used to keep the conversation on course. However, each interview varied greatly depending on that person's personal and professional context and experiences. The interviews were audio-recorded, with permission, for record purposes and field notes were taken by hand. All records were allocated to the interview code (for example, I01) rather than the interviewees' names, to ensure confidentiality and to track each piece of data through the chain of evidence and various stages of analysis (see 4.3.1).

The data collected included details on the respondent's job role, their use of spatial and property information, how this data flows through the CCT and how their work fits into the greater PMS. This data was fed into the case study to create the detailed model of the current CCT PMS (see Section 4.3). Furthermore, the interviews collected data on the respondents' views on introducing a 3D Property Management Object (PMO), any potential benefits or pitfalls that they could see, and their experiences of any current 3D use cases that illustrate the usefulness (or not) of 3D. If new information arose at a later stage, follow-up interviews were conducted with the participant, typically using electronic communication. However, due to time and resource constraints, this was not the norm and one interview was typically sufficient to gain the necessary data.

Section 4.3 Data Integration and the Analytical Framework

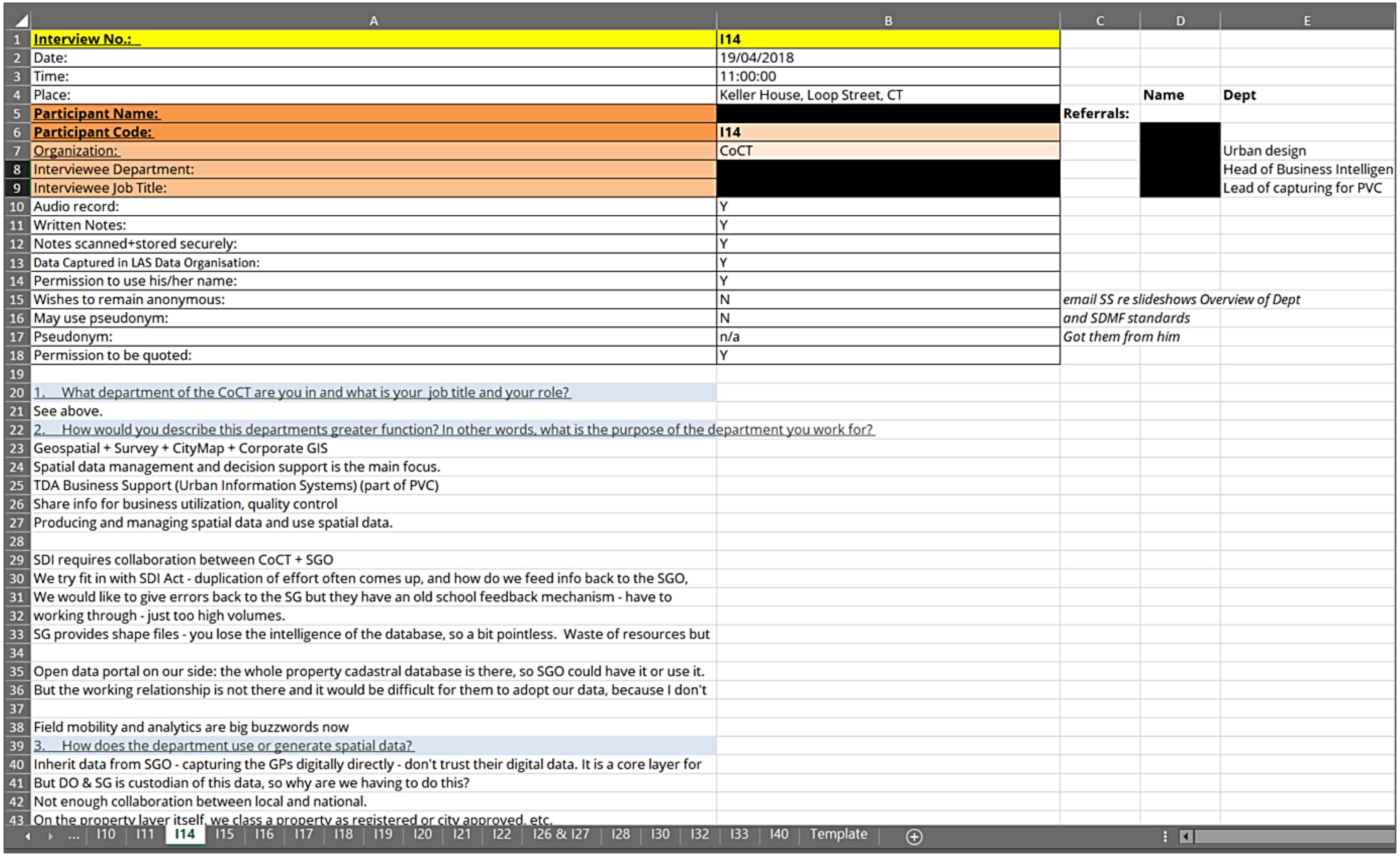
The integration of the data collected is an integral step in MMR, as discussed in 3.3.3. The different parts of the chain of evidence (see 3.3.3iii) that made up the data organisation and analysis process are presented below. A research database was established in which all documentation evidence is logged and encoded, and referenced to an interview code, if relevant. It must be noted that the process did not use coding software but hard copy notes and manual coding processes relying on the researcher's extraction of meaning and interpretation of the data. The case study database(see 3.3.3iii) was, therefore, pragmatically extended to include all the data collected, creating a formal record that can be referenced by other researchers. This database increases the study's reliability and aids in building the chain of evidence.

4.3.1 WITHIN-CASE ANALYSIS AND THE CHAIN OF EVIDENCE

Within-case analysis of the CCT Property Management System (PMS) was performed in a reflective, repetitive manner while building the chain of evidence and included the interview, documentary, visual and observation data. The chain of evidence records the path taken by the researcher, increasing the study results' reliability and construct validity. The analysis performed was facilitated by building the chain of evidence as follows:

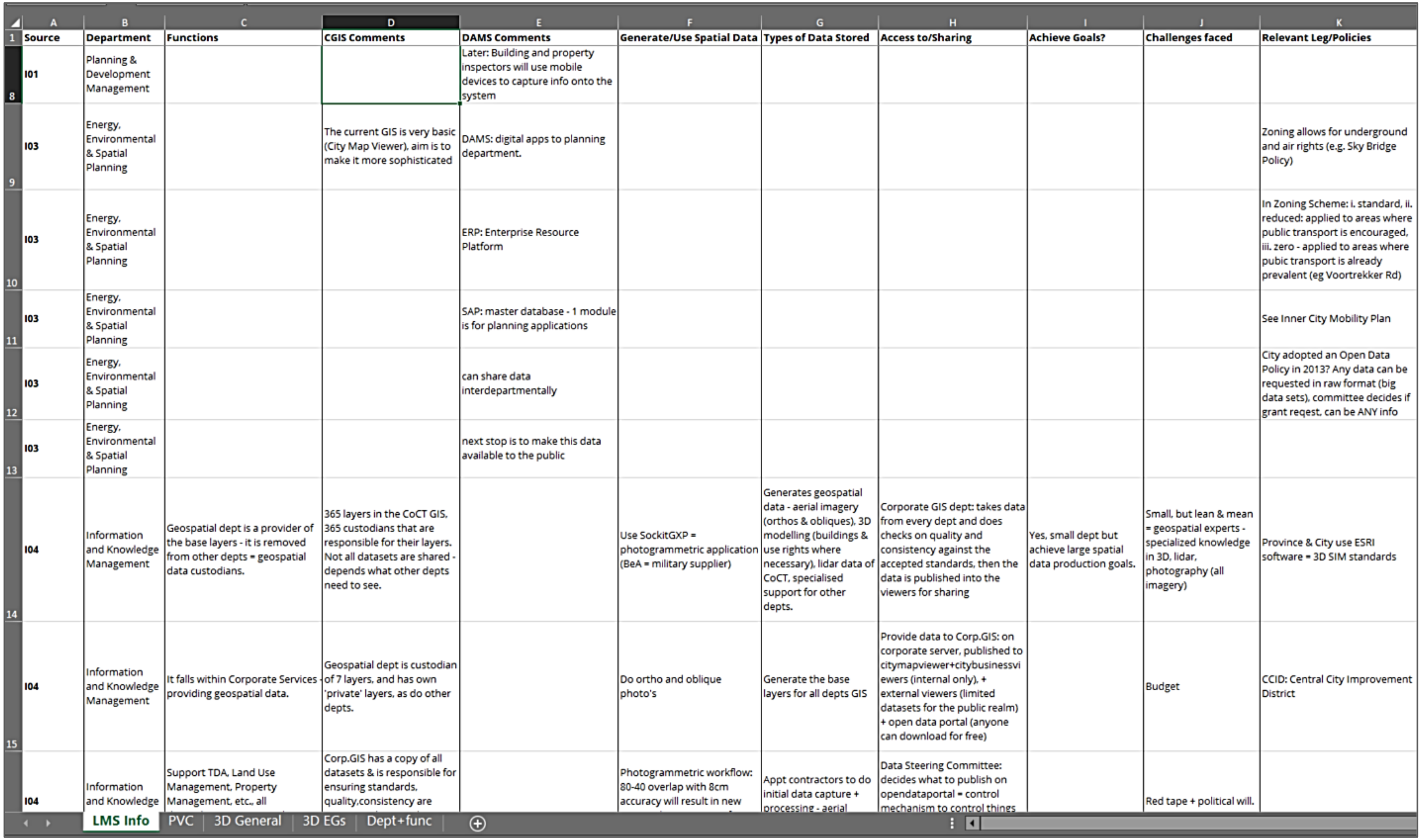
1. *Table of Interview Notes* (Figure 4-1): Each interview was transcribed into a separate spreadsheet directly from the field notes and the audio recording. Thematic inductive analysis was used to identify themes in this table from both the interview guide and any common trends that came up in the interviews. The research objectives were used to identify the themes and commonality was used to sort the data that came out of the interviews. Outliers were highlighted for investigation – outliers cannot be ignored in exploratory research because they may offer insight that has been unknown up until that point.

2. The *LAS Data Organisation* table (Figure 4-2): The interview data was then extracted from the individual spreadsheets into a second table that grouped data by the identified themes. The spreadsheet contains a different sheet for each section of the research, namely: PMS information (see Chapter 5); the Property Value Chain (see Section 5.3); general 3D (see Chapter 6); and 3D use cases (see Section 6.1). Within each sheet, every column is assigned a theme, as identified in the *Table of Interview Notes*. The data collected is organized and inserted under the relevant theme along each row. Any relevant documentation, for example, an organogram, is listed in this table under the relevant theme for reference at a later stage. The interviewee code was retained in each row to preserve a connection to the source in the chain of evidence. This table allowed the narratives held within the interview data to begin forming for each theme.



	A	B	C	D	E
1	**Interview No.:**	**I14**			
2	Date:	19/04/2018			
3	Time:	11:00:00			
4	Place:	Keller House, Loop Street, CT		**Name**	**Dept**
5	**Participant Name:**	[redacted]	**Referrals:**		
6	**Participant Code:**	**I14**		[redacted]	
7	Organization:	CoCT		[redacted]	Urban design
8	Interviewee Department:	[redacted]		[redacted]	Head of Business Intelligen
9	Interviewee Job Title:	[redacted]		[redacted]	Lead of capturing for PVC
10	Audio record:	Y			
11	Written Notes:	Y			
12	Notes scanned+stored securely:	Y			
13	Data Captured in LAS Data Organisation:	Y			
14	Permission to use his/her name:	Y			
15	Wishes to remain anonymous:	N	*email SS re slideshows Overview of Dept*		
16	May use pseudonym:	N	*and SDMF standards*		
17	Pseudonym:	n/a	*Got them from him*		
18	Permission to be quoted:	Y			
19					
20	1. What department of the CoCT are you in and what is your job title and your role?				
21	See above.				
22	2. How would you describe this departments greater function? In other words, what is the purpose of the department you work for?				
23	Geospatial + Survey + CityMap + Corporate GIS				
24	Spatial data management and decision support is the main focus.				
25	TDA Business Support (Urban Information Systems) (part of PVC)				
26	Share info for business utilization, quality control				
27	Producing and managing spatial data and use spatial data.				
28					
29	SDI requires collaboration between CoCT + SGO				
30	We try fit in with SDI Act - duplication of effort often comes up, and how do we feed info back to the SGO,				
31	We would like to give errors back to the SG but they have an old school feedback mechanism - have to				
32	working through - just too high volumes.				
33	SG provides shape files - you lose the intelligence of the database, so a bit pointless. Waste of resources but				
34					
35	Open data portal on our side: the whole property cadastral database is there, so SGO could have it or use it.				
36	But the working relationship is not there and it would be difficult for them to adopt our data, because I don't				
37					
38	Field mobility and analytics are big buzzwords now				
39	3. How does the department use or generate spatial data?				
40	Inherit data from SGO - capturing the GPs digitally directly - don't trust their digital data. It is a core layer for				
41	But DO & SG is custodian of this data, so why are we having to do this?				
42	Not enough collaboration between local and national.				
43	On the property layer itself, we class a property as registered or city approved, etc.				

Figure 4-1: *Table of Interview Notes* screenshot



	A	B	C	D	E	F	G	H	I	J	K
1	**Source**	**Department**	**Functions**	**CGIS Comments**	**DAMS Comments**	**Generate/Use Spatial Data**	**Types of Data Stored**	**Access to/Sharing**	**Achieve Goals?**	**Challenges faced**	**Relevant Leg/Policies**
8	**I01**	Planning & Development Management			Later: Building and property inspectors will use mobile devices to capture info onto the system						
9	**I03**	Energy, Environmental & Spatial Planning		The current GIS is very basic (City Map Viewer), aim is to make it more sophisticated	DAMS: digital apps to planning department.						Zoning allows for underground and air rights (e.g. Sky Bridge Policy)
10	**I03**	Energy, Environmental & Spatial Planning			ERP: Enterprise Resource Platform						In Zoning Scheme: i. standard, ii. reduced: applied to areas where public transport is encouraged, iii. zero - applied to areas where pubic transport is already prevalent (eg Voortrekker Rd)
11	**I03**	Energy, Environmental & Spatial Planning			SAP: master database - 1 module is for planning applications						See Inner City Mobility Plan
12	**I03**	Energy, Environmental & Spatial Planning			can share data interdepartmentally						City adopted an Open Data Policy in 2013? Any data can be requested in raw format (big data sets), committee decides if grant reqest, can be ANY info
13	**I03**	Energy, Environmental & Spatial Planning			next stop is to make this data available to the public						
14	**I04**	Information and Knowledge Management	Geospatial dept is a provider of the base layers - it is removed from other depts = geospatial data custodians.	365 layers in the CoCT GIS. 365 custodians that are responsible for their layers. Not all datasets are shared - depends what other depts need to see.		Use SockitGXP = photogrammetric application (BeA = military supplier)	Generates geospatial data - aerial imagery (orthos & obliques), 3D modelling (buildings & use rights where necessary), lidar data of CoCT, specialised support for other depts.	Corporate GIS dept: takes data from every dept and does checks on quality and consistency against the accepted standards, then the data is published into the viewers for sharing	Yes, small dept but achieve large spatial data production goals.	Small, but lean & mean = geospatial experts - specialized knowledge in 3D, lidar, photography (all imagery)	Province & City use ESRI software = 3D SIM standards
15	**I04**	Information and Knowledge Management	It falls within Corporate Services - providing geospatial data.	Geospatial dept is custodian of 7 layers, and has own 'private' layers, as do other depts.		Do ortho and oblique photo's	Generate the base layers for all depts GIS	Provide data to Corp.GIS: on corporate server, published to citymapviewer+citybusinessviewers (internal only), + external viewers (limited datasets for the public realm) + open data portal (anyone can download for free)		Budget	CCID: Central City Improvement District
	I04	Information and Knowledge	Support TDA, Land Use Management, Property Management, etc., all	Corp.GIS has a copy of all datasets & is responsible for ensuring standards, quality,consistency are		Photogrammetric workflow: 80-40 overlap with 8cm accuracy will result in new	Appt contractors to do initial data capture + processing - aerial	Data Steering Committee: decides what to publish on opendataportal = control mechanism to control things		Red tape + political will.	

Figure 4-2: *LAS Data Organisation table* screenshot

3. The data books, *Themes of the CCT PMS* (Figure 4-3) and *3D Themes* (Figure 4-4): From the *LAS Data Organisation* table, the researcher organised and rewrote the themed data into each data book to further familiarize herself with the data, draw out patterns and extract further meaning. Two data books were created, one for the CCT PMS related data, as presented in Chapter 5, and another for data related to the 3D themes, as presented in Chapter 6. The data books were organized by one major theme per page (see Figure 4-3: the labels indicate the page themes) and common ideas were grouped together and highlighted using thematic structuring (see Figure 4-4). Outliers were included and highlighted because, as noted above, this research is exploratory and data may appear as an outlier only because it has not been thought of previously or is not commonly acknowledged information. Every item transcribed in the data books was referenced to the original interview code to preserve the connection to the source data in the chain of evidence. Additionally, the documentary evidence and personal experiences were introduced and tied to the interview data in the data books, helping to corroborate the interview data, build the case study narrative and the concepts around the uses of a 3D city. Furthermore, the LAS theory (Section 3.1) and literature reviewed in Chapter 2 , for example specific GGPs or the SDGs, were linked to relevant items and noted in the margins for ease of reference when writing up Chapter 7.

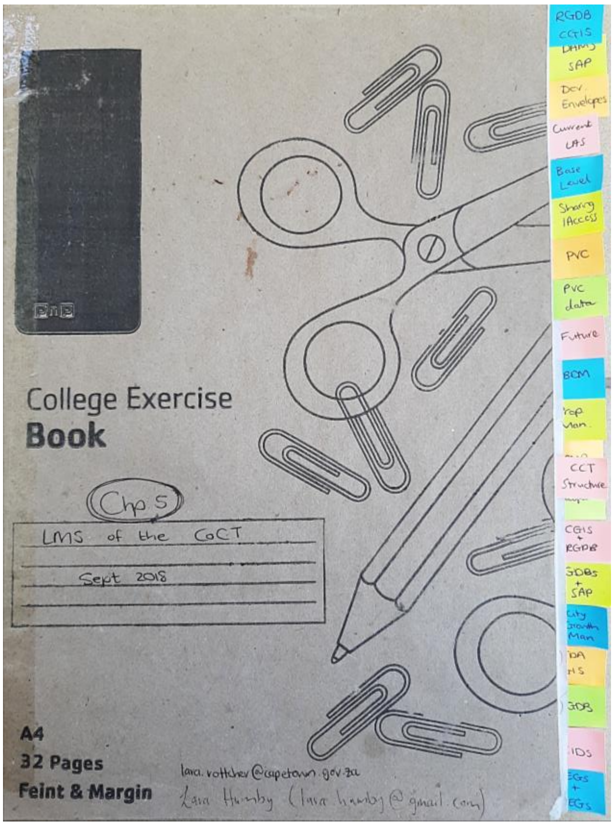
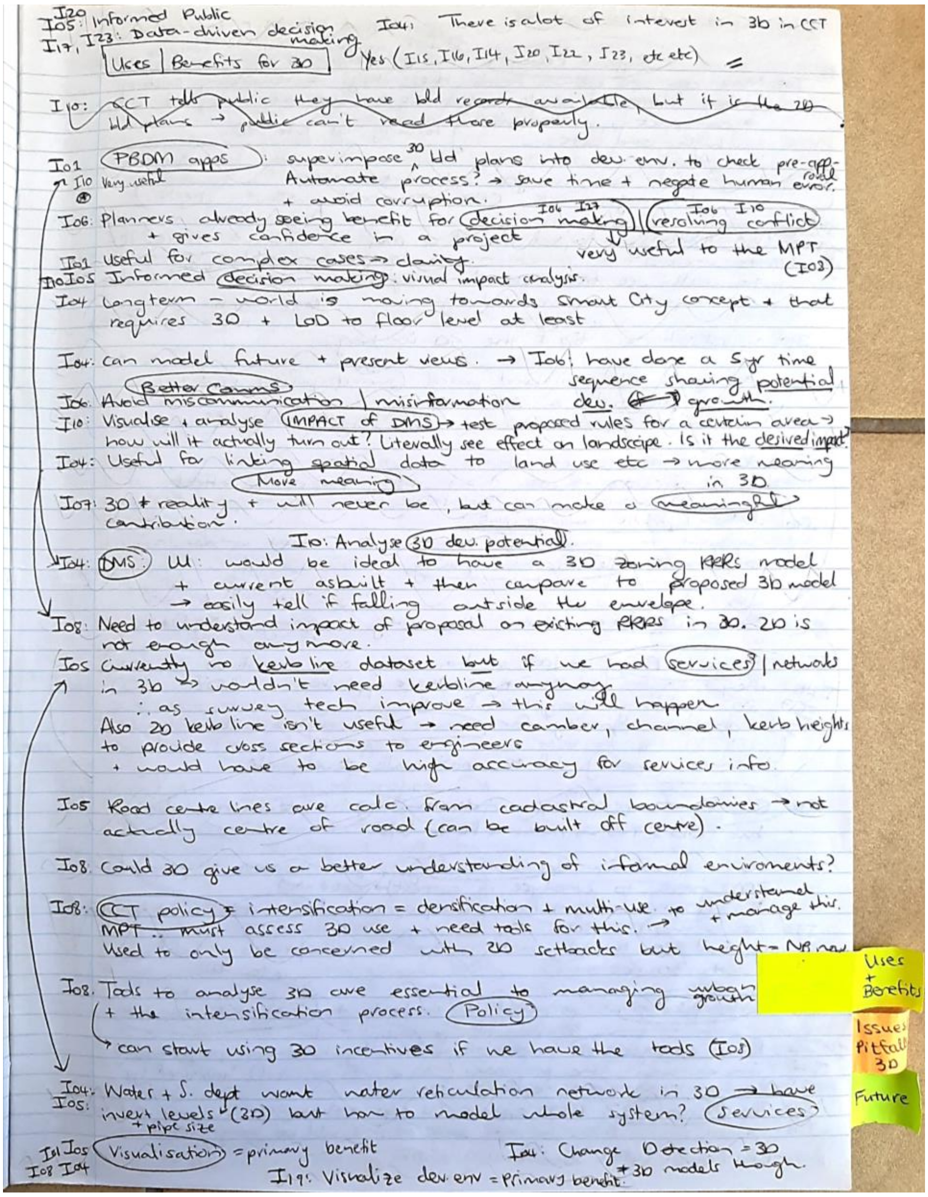


Figure 4-3: Cover of the *Themes of the CCT PMS* book

4. *The potential benefits and pitfalls of introducing 3D* table (Figure 4-5): For Chapter 6, a third spreadsheet was created to tabulate and organize all data collected from the interviews relating to the potential benefits or pitfalls that introducing 3D may have, as drawn from the *3D Themes* data book. The aim was to assess the interviewees' opinions regarding 3D. As mentioned in 4.2.3i, the interviewees selected have specific roles or insights into land administration and 3D. Were 3D to be implemented into the CCT PMS, this group would be among the first to create, use and promote a 3D city model. Therefore, the thoughts and opinions of this group would be vital to introducing 3D and should be acknowledged and addressed. Tabulating this data allowed the researcher to organize the most common themes that were at the forefront of the interviewees' minds when considering 3D. Outliers were included for reasons discussed above. The final outputs are the graphs presented in Chapter 6.



I20
I05: Informed Public
I17, I23: Data-driven decision making

I04: There is alot of interest in 3D in CCT
Yes (I15, I16, I14, I20, I22, I23, etc etc) =

Uses | Benefits for 3D

I10: ~~CCT tells public they have bld records available, but if is the 2D bld plans → public can't read these properly.~~

I01 (PBDM apps): superimpose 3D bld plans into dev. env. to check pre-approval
I10 Very useful
Automate process? → save time + negate human error.
+ avoid corruption.

I06: Planners already seeing benefit for (decision making) I06 I27 || (resolving conflict) I06 I10
+ gives confidence in a project
very useful to the MPT (I08)

I01 Useful for complex cases ⇒ clarity.

I10 I05 Informed (decision making): visual impact analysis.

I04 Longterm – world is moving towards Smart City concept + that requires 3D + LoD to floor level at least

I04: can model future + present views. → I06: have done a 5yr time sequence showing potential dev. growth.

(Better Comms)
I06: Avoid miscommunication | misinformation

I10: Visualise + analyse (IMPACT of DMS) → test proposed rules for a certain area → how will it actually turn out? Literally see effect on landscape. Is it the desired impact?

I04: Useful for linking spatial data to land use etc → more meaning in 3D.
(More meaning)

I07: 3D ≠ reality + will never be, but can make a (meaningful) contribution.

I10: Analyse (3D dev. potential).

I04: (DMS) UI: would be ideal to have a 3D zoning RRRs model + current asbuilt + then compare to proposed 3D model → easily tell if falling outside the envelope.

I08: Need to understand impact of proposal on existing RRRs in 3D. 2D is not enough anymore.

I05 Currently no kerb line dataset but if we had (services) | networks in 3D ⇒ wouldn't need kerbline anyway
∴ as survey tech improve → this will happen
Also 2D kerb line isn't useful → need camber, channel, kerb heights to provide cross sections to engineers
+ would have to be high accuracy for services info.

I05 Road centre lines are calc. from cadastral boundaries → not actually centre of road (can be built off centre).

I08. Could 3D give us a better understanding of informal environments?

I08: (CCT policy) ≠ intensification = densification + multi-use to understand + manage this.
MPT ∴ must assess 3D use + need tools for this. →
Used to only be concerned with 2D setbacks but height = NB now

I08. Tools to analyse 3D are essential to managing urban growth + the intensification process. (Policy)
→ can start using 3D incentives if we have the tools (I08)

I04: I05: Water + S. dept want water reticulation network in 3D → have invert levels + pipe size (3D) but how to model whole system? (Services)

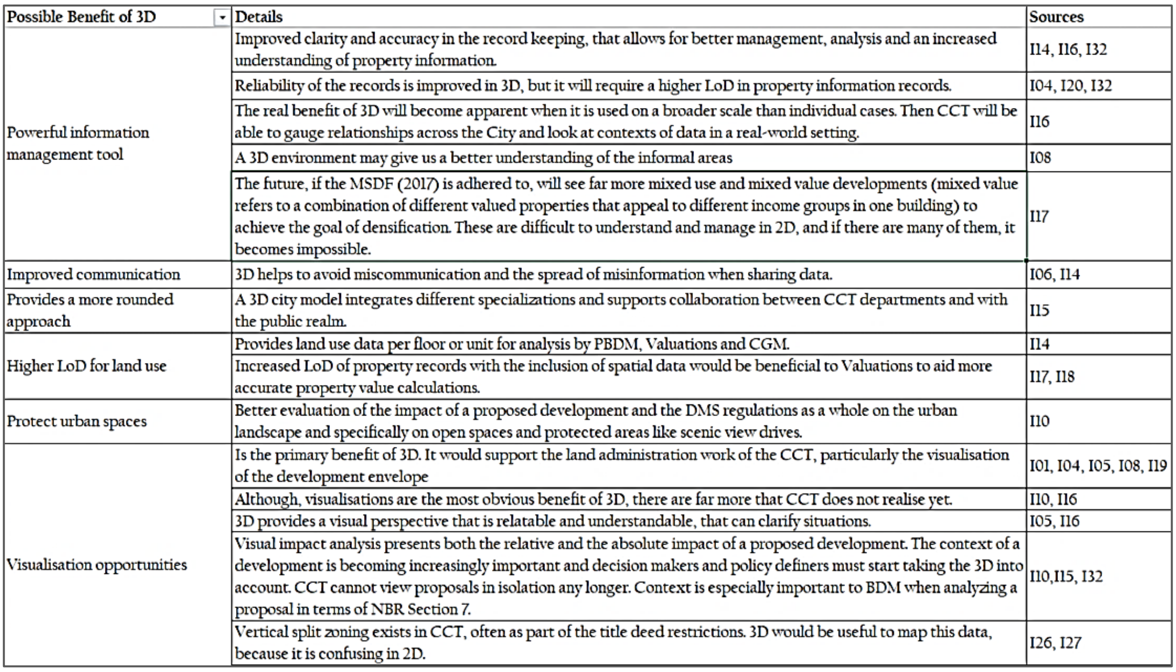
I01 I05 I08 I04 (Visualisation) = primary benefit

I04: Change Detection = 3D + 3D models though.

I19: Visualize dev. env = Primary benefit.

Figure 4-4: A page from the *3D Themes* book

Importantly, the researcher stepped back to the *Table of Interview Notes* at stages during the data processing to re-check that all data had been captured correctly, under the correct theme. If there was any doubt as to the intended meaning of a statement, the researcher returned to the interview recording and/or contacted the interviewee for clarification. Therefore, the data processing was cyclical and reflective, moving through the tables and onto the data books, and then into the interviews, sometimes adding new interviews and data, and then back to the tables and data books, inputting or editing data. Therefore, the researcher moved pragmatically between different phases of processing, analysis and data collection as the study developed, as recommended by Neuman (2000) and Yin (2003) for mixed methods and case study research.



Possible Benefit of 3D	Details	Sources
Powerful information management tool	Improved clarity and accuracy in the record keeping, that allows for better management, analysis and an increased understanding of property information.	I14, I16, I32
	Reliability of the records is improved in 3D, but it will require a higher LoD in property information records.	I04, I20, I32
	The real benefit of 3D will become apparent when it is used on a broader scale than individual cases. Then CCT will be able to gauge relationships across the City and look at contexts of data in a real-world setting.	I16
	A 3D environment may give us a better understanding of the informal areas	I08
	The future, if the MSDF (2017) is adhered to, will see far more mixed use and mixed value developments (mixed value refers to a combination of different valued properties that appeal to different income groups in one building) to achieve the goal of densification. These are difficult to understand and manage in 2D, and if there are many of them, it becomes impossible.	I17
Improved communication	3D helps to avoid miscommunication and the spread of misinformation when sharing data.	I06, I14
Provides a more rounded approach	A 3D city model integrates different specializations and supports collaboration between CCT departments and with the public realm.	I15
Higher LoD for land use	Provides land use data per floor or unit for analysis by PBDM, Valuations and CGM.	I14
	Increased LoD of property records with the inclusion of spatial data would be beneficial to Valuations to aid more accurate property value calculations.	I17, I18
Protect urban spaces	Better evaluation of the impact of a proposed development and the DMS regulations as a whole on the urban landscape and specifically on open spaces and protected areas like scenic view drives.	I10
Visualisation opportunities	Is the primary benefit of 3D. It would support the land administration work of the CCT, particularly the visualisation of the development envelope	I01, I04, I05, I08, I19
	Although, visualisations are the most obvious benefit of 3D, there are far more that CCT does not realise yet.	I10, I16
	3D provides a visual perspective that is relatable and understandable, that can clarify situations.	I05, I16
	Visual impact analysis presents both the relative and the absolute impact of a proposed development. The context of a development is becoming increasingly important and decision makers and policy definers must start taking the 3D into account. CCT cannot view proposals in isolation any longer. Context is especially important to BDM when analyzing a proposal in terms of NBR Section 7.	I10,I15, I32
	Vertical split zoning exists in CCT, often as part of the title deed restrictions. 3D would be useful to map this data, because it is confusing in 2D.	I26, I27

Figure 4-5: *The Potential 3D Benefits & Pitfalls* table screenshot

4.3.2 THE SYSTEMS-THINKING TOOLS ADOPTED

The systems-thinking tools employed to investigate and model the CCT PMS were SSM rich pictures and the BPM data flow diagrams (DFDs)(see Section 3.4). As mentioned, documentary evidence was vital to the modelling of the CCT PMS. The data collected, processed, organised and filtered into the *Themes of the CCT PMS* book was used, together with the system models produced using systems-thinking, to inform the narrative describing the CCT LMS as set out in Chapter 5.

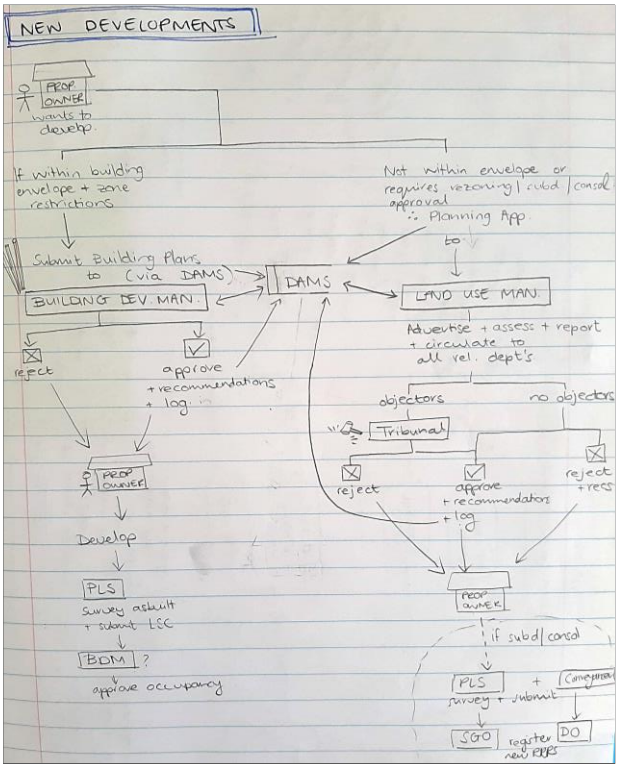


Figure 4-6: Example of a rich picture

i THE USE OF INVESTIGATIVE SSM RICH PICTURES

The two initial steps of SSM are pragmatically employed in this study (see 3.4.1):

i. Investigate the Problem (gather information and views on the existing problem and system), and
ii. Structure the Problem Statement (using rich pictures to gain an understanding of the 'real-world' system-in-focus and its relationships).

Initially, rich pictures were used to identify the primary subsystems with the PMS that have a hand in managing the Property Management Object (PMO) and through this, the initial interview candidates were identified. As an analysis tool, multiple rich picture diagrams were drawn from different perspectives to make sense of the data collected on the various subsystems and, specifically, the flow of property information in the CCT PMS (see

Figure 4-6). The rich pictures assisted in highlighting important subsystems in the system-in-focus and where problem areas might be in the flow of property data. Furthermore, these diagrams informed the decomposition diagrams and the larger overview DFD of the CCT PMS in the BPM detailed below.

ii THE USE OF BPM DATA FLOW DIAGRAMS TO MODEL THE CCT PMS

The objective here was to follow the process, including the flow, use and transformation, of property information within the CCT PMS. Initially, informal decomposition diagrams were used to identify the structure of the subsystems and sub-processes (see Figure 4-7), and plan the larger overview diagram of the PMS. These were then combined into a DFD of the whole CCT PMS, including each subsystem (see Figure 4-8). The researcher made use of moveable markers and pencil to create this overview diagram, allowing the researcher to easily change and move items in the diagram. It allowed for flexibility in the processing to fit in new or alternative information. The diagram was edited throughout the data processing phase of the research; as new information was extracted from the data sourced. The diagram was in editing mode for approximately 10 months until the data processing and analysis was completed. This diagram directly informed the final model that can be seen in Chapter 5. The final model clearly illustrates the subsystems and data flows identified through the data analysis processes.

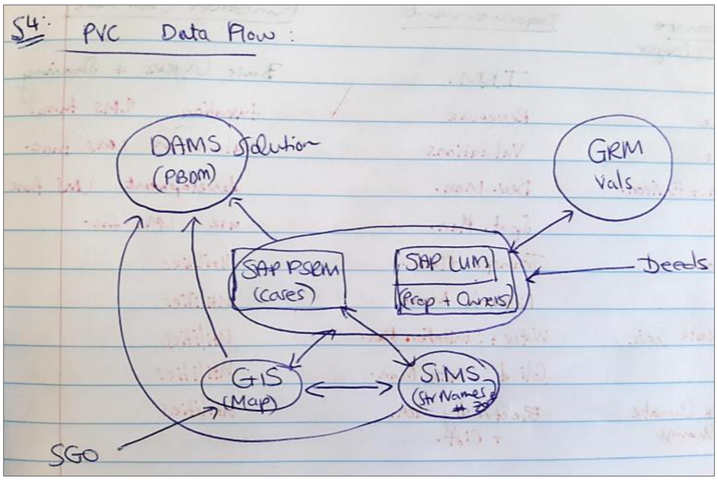


Figure 4-7: Example of a decomposition diagram

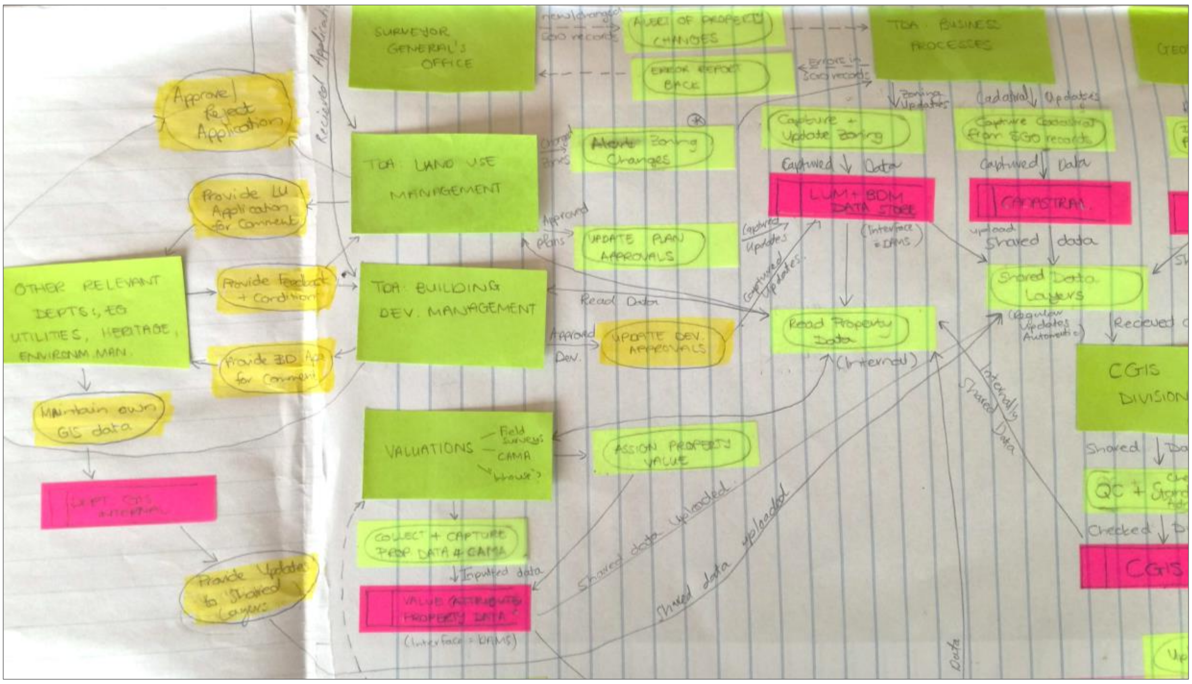


Figure 4-8: A section of the final rough data flow diagram (DFD) representing the CCT PMS showing the use of moveable labels and pencil to facilitate easy editing through the data collection and analysis processes.

4.3.3 TRIANGULATION IN THE STUDY

Data triangulation was employed by using in-depth interviews, direct and participant observation, and documentary sources, including visuals, as sources of data (see Section 4.2). The researcher combined the data into the chain of evidence, as described above, allowing different sources to corroborate or disprove information collected. For example, interviewees may seem to disagree on how the CCT GIS functions, but using documentary evidence to ground the data collected clears the confusion and cements the 'truth' of the situation. The interviewees do state what they deem to be 'true', even though it is rather a matter of opinion. It was important for the researcher to corroborate the interview data with documentary evidence, particularly for the system analysis of the CCT PMS. This was successfully done and the different data sources were found to complement each other. Furthermore, methodological triangulation (see 3.3.3ii) was incorporated by pragmatically combining case study analysis techniques (see 4.3.1) with systems theory analysis techniques (see 4.3.2).

4.3.4 THE LAND ADMINISTRATION SYSTEMS THEORY AS AN ANALYTICAL FRAMEWORK

This study adopted the LAS theory presented in Section 3.1 as an analytical framework against which the current CCT PMS and its capabilities with respect to both the land administration functions and the third dimension was analysed. The LAS theory, including LAS, LMP, RRRs, SDI and GGPs, provides a backdrop against which the current CCT PMS can be viewed and evaluated. The conclusions drawn in the research were evaluated in comparison to these adopted standards and best practices, allowing for a deeper understanding and analysis of the data, while increasing the study validity and generalizability. It must be noted that this study did not attempt to test or critique these theories. Rather this research uses the LAS theory to assess the single case study and whether the LAS functions are fully realised in the current 2D system.

The LMP sets a standard against which the PMS was evaluated based on whether it holistically achieves its land administration goals in line with the GGPs. This study adopted the GGPs as summarised in Hull and Whittal (2013)(see 3.1.4). The PMS's performance was assessed against the GGPs to increase the depth of understanding of how well the PMS achieves its goals with respect to governance. Furthermore, the facilitation of the RRRs in the CCT PMS was analysed to assess any existing issues within the system, particularly with respect to the third dimension.

Specifically, the researcher used a number of points in the data processing and analysis phases to draw links between the LAS theory (Section 3.1), for example specific GGPs or the LMP, and the data collected and processed. This included making links and noting in the margins of the data books, as discussed in 4.3.1. Furthermore, after Chapter 5 and Chapter 6 were written, the researcher made further links to the theory and noting in the margins of those chapters on a hardcopy version. These methods of linking the theory to the data were simple and yet effective, and eased the writing of the analysis in Chapter 7.

Section 4.4 Ethics and Bias in this Research

4.4.1 THE POTENTIAL OF BIAS IN THIS RESEARCH

The researcher has some experience conducting case study research; see Humby (2014). However, the researcher has no experience of in-depth interviewing, and little experience in the application of MMR. Therefore, there may be a tendency to lean more towards familiar methods or theories over others that are unfamiliar and therefore more challenging (Neuman, 2000; Whittal, 2008). This was combated by a rigorous research design; a good deal of practice in new methods (for example, with the adopted systems modelling tools); supervisor support and guidance; and a statement of all possible biases that could undermine the quality of the investigation.

The researcher is a professional land surveyor employed by the CCT since August 2018 and was previously employed at the Surveyor-General's Office. While employment at the CCT allowed for easier networking with potential participants and access to essential data and resources, it does present a risk of bias based on familiarity. Furthermore, the researcher acknowledges that in many cases, the individuals interviewed were likely to have superior knowledge, experience and be positioned higher in the organisation than the researcher. This can cause bias in the interviews, as the researcher may not be able to engage on an equal level. The researcher makes use of a semi-structured interview guide to avoid this issue. Whittal (2008) recommends the use of expert key informants from different backgrounds as sources of data to gain a variety of perspectives and knowledge, thereby combating the risk of researcher bias. This approach was adopted.

Additionally, the researcher has been personally involved with a number of the 3D use cases. While this allows for a unique perspective and observation of the cases and their context, it presents a risk of observer bias. Furthermore, she is a member of the CCT Smart City work group investigating the possibility of introducing 3D to the CCT and this adds to the risk of bias.

A rigorous research design and the use of triangulation assists in using the bias to aid the research process rather than hinder it (Whittal, 2008). As discussed, data collection was triangulated by using documentation, observation and in-depth interviews. Furthermore, the single case study method, including the chain of evidence and within-case analysis, was integrated with both SSM and BPM systems approaches, resulting in method triangulation. Additionally, bias is reduced by referring to the LAS theoretical framework as a basis to the study. The employment of this combination of tools, methods and theory increases the reliability and validity of the inferences drawn and thereby increases the quality of the MMR conducted.

4.4.2 ETHICS AND RESEARCH APPROVALS

The researcher made the necessary and appropriate ethics and research applications to both the University of Cape Town and the City of Cape Town. Both applications were approved by the institutions (see *Appendix E*).

Section 4.5 Conclusion

This chapter presents how the adopted methodology was applied to facilitate the analysis and modelling of the current CCT Property Management System (PMS) with a focus on the flow of property information, and an analysis of the current use of 3D data and the potential benefits or disadvantages that 3D may introduce. A MMR framework grounded in pragmatism using a single-case study design combined with in-depth interviews and systems-thinking thinking tools were used to collect and process data and model the current CCT PMS, while the LAS best practices such as LMP, GGPs and RRRs were used to evaluate that system and its ability to achieve the land administration goals.

Chapter 5 THE CCT PROPERTY MANAGEMENT SYSTEM, THE PROPERTY MANAGEMENT OBJECT AND DATA FLOWS

Chapter 5 presents data collected and processed in a single-case study to illustrate the current state of the CCT Property Management System (PMS), and the lifecycle[18] of the Property Management Object (PMO) within that system. The data presented here was sourced from in-depth interviews, personal work experience[19] and documentation including organisation structures, workflows and policies. Using rich pictures, tables and BPM, the data was combined into the narrative form presented here. Chapter 4 presents the adopted methodology.

Section 5.1 The Case Study Description: The CCT PMS

5.1.1 AN INTRODUCTION TO THE SYSTEM OF SOUTH AFRICAN GOVERNANCE

The SA government is divided into three spheres (see Figure 5-1) that operate on a separation of powers basis as set by the Constitution (*Constitution of the Republic of South Africa*, 1996).

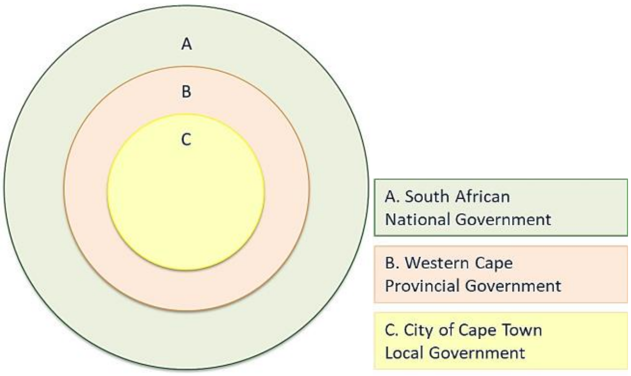


Figure 5-1: The three spheres of South African government

The three spheres of government are:

A. National government is the outer sphere within which all other spheres must act. National legislation is enacted at this level. The national government is responsible for the primary land management function, land tenure, within the Land Tenure System (LTS)(see 5.1.2);

B. Provincial governments: each of the nine provinces of SA is governed individually within national legislation. Provincial legislation is enacted at this level; and

C. Local governments: SA is wholly divided into municipal areas; each being managed by a local government administration. Every local council acts within national legislation but adopts and applies these laws in individual approaches by implementing local-level legislation in the form of municipal by-laws.[20] Thus, each local government's approach can be quite different from the next. However, the responsibilities that local government is burdened with are constant. Each municipality is responsible for the land administration functions of land use, development and valuation within its PMS.

The CCT local government is adopted in Chapter 1 as the focus for analysing a PMS and the lifecycle of the PMO.

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[18] As defined in *Appendix A: Operating Definitions*.

[19] Any data drawn from personal experiences is referenced as interviewee I50.

[20] For example, the Municipal Planning By-law (*MPB*, 2015) is the CCT's application of the national Spatial Planning and Land Use Management Act 16 of 2013 (*SPLUMA*, 2013).

5.1.2 AN INTRODUCTION TO THE LAND TENURE SYSTEM & LEGAL PROPERTY OBJECT

The SA Land Tenure System (LTS) and land law is discussed in Humby (2014;2017) and Fisher *et al.* (2020). These should be referred to for a deeper understanding of real property in the SA context.

i THE SOUTH AFRICAN LAND TENURE SYSTEM

The maintenance of the SA LTS is a state responsibility. The land administration function of land tenure is achieved through the recording of real property rights in both a title deed and a diagram (Hull & Whittal, 2013). The deed is a textual description of the real property rights and the holder of those RRRs. The deed is registered and held in the Deeds Office registry. The diagrammatical and numerical evidence of the extent of real rights is held at the Surveyor General's Office in the form of approved diagrams, general plans or sectional title plans that form the cadastre.[21] The two offices work together to achieve the function of land tenure, however the registers are held and maintained separately, linked by the unique erf number attached to the parcel (Ibid.).

SA has a world-class cadastre and registry that ensures tenure security (Zevenbergen, 2002). However, with regards to technological advancements within land administration, SA is falling behind. The registry and cadastre are as yet paper-based, although these documents are scanned and available electronically, and the numerical data is captured in a rudimentary GIS [22] (I05). The GIS records have no legal weight and therefore little care is given to the accuracy, consistency and standard of the data (I14,I50).

ii THE LEGAL PROPERTY OBJECT

Registered real property RRRs are tied to the land parcel and are inseparable from it. These RRRs are registered in 2D but are implied in 3D, creating a conceptual Legal Property Object (LPO). Permanent constructions attached to the land are part of the real property in law; and thus, the registry and cadastre do not record any data on physical constructions unless these are relevant to the property boundaries (Humby, 2014).

Over the years, it has become necessary to create separable RRRs that overlap with the surface parcel, and there are a set of legal tools that can be employed to achieve horizontal stratification of property. For example, an apartment is capable of separate ownership using sectional title. However, the apartment LPO cannot be severed from the erf and therefore, it is not an independent ownership-entity (Humby, 2014). Humby (2014) illustrates that these tools are insufficient to providing clear, accurate records and tenure security in complex 3D RRRs situations. Tenure insecurity has broad knock-on effects throughout society and should be avoided at all costs (Simpson & Sweeney, 1973). Thus, Humby (2014) argued there is a need for a 3D record in the cadastre and LTS.

5.1.3 AN INTRODUCTION TO THE CCT PROPERTY MANAGEMENT SYSTEM

The City of Cape Town (CCT) is a metropolitan local government that governs an area of 2700 square kilometres and a population of approximately 4.7 million. The metropole is located between high mountain ranges and the Atlantic Ocean, placing inherent geographic limits upon the City's extents and growth potential. The land administration functions of land use, development and value are the responsibility of two directorates, Planning and Building Development Management (PBDM) and Finance. PBDM is responsible for the land use and development functions within the Property Management System (PMS) and these are performed by the Business Systems, Land Use Management (LUM) and Building Development Management (BDM) departments. The final

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[21] The cadastre is defined in Chapter 3.
[22] MapGuide, an AutoDesk product.

PMS function, land valuation, is the responsibility of Valuations and Revenue departments within the Finance directorate. These five departments form the so-called Property Value Chain. [23] Therefore, the Property Value Chain is the focus of the Property Management System (PMS) and Property Management Object (PMO) narrative.

Although the majority of CCT departments use and/or generate spatial information,[24] these five departments use and/or generate property-specific information and therefore contribute directly to the PMO and are included in the PMS. Other departments may make use of the PMO data,[25] but are not contributors to the PMO and are held external to the PMS. The departments that make up the PMS, mostly fall within the Property Value Chain, with the exception of the Information & Knowledge Management department. This department that creates the foundation geospatial datasets that contribute to the PMO and controls the sharing of CCT data. These departments will be introduced in 5.3.1.

5.1.4 CCT Policies and Strategies for Development

The Integrated Development Plan (*IDP*, 2017) and the Municipal Spatial Development Framework (*MSDF*, 2017) set out the vision and spatial development goals that guide development over a five-year period (currently 2017-2022). The Spatial Development Framework (2017: 2) is the "spatial interpretation" of the Integrated Development Plan. PBDM defines the desired urban form and this informs the CCT policies like the Spatial Development Framework that guide development (I10).

For the current period, the primary aim is to achieve spatial transformation through intensified development and transport-orientated growth (*IDP*, 2017; *MSDF*, 2017). Intensification requires both the horizontal and vertical densification[26] of property and the diversification of land use (I01,I03,I23)(*MSDF*, 2017). It has been recognised that urban sprawl results in "unsustainable operational costs" (*MSDF*, 2017: 3) and therefore, the CCT are promoting high-density, mixed-use development.[27] Importantly, the Spatial Development Framework (2017) aims to identify underutilized development opportunities as part of immediate implementation action (I18). Furthermore, the Integrated Development Plan (2017) highlights the importance of analysing the environmental impact of new developments.

The Spatial Development Framework goal of land use densification and diversification is supported by CCT policies that specify the how and why to achieve that aim. Objective 5 of the Urban Design Policy (*UDP*, 2013) specifically promotes diversification, intensification and adaptability of urban development. The Densification Policy (*DP*, 2012) sets out specific rules for densification of the urban form. The Densification Policy and the Urban Design Policy include the requirement that a proposal should maximise height and bulk while taking into account the potential effect on the character of the immediate urban context. Additionally, the Densification Policy states that densification should promote mixed land uses and protect natural and "significant cultural landscapes" (2012: 13). It goes further to say that densification should not be to the detriment of the mountain

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[23] For more refer to in *Appendix C*.
[24] As defined in *Appendix A*.
[25] There are numerous CCT departments that make use of the PMO (see *Appendix C*).
[26] As defined in the CCT Densification Policy (*DP*, 2012).
[27] Defined in the CCT Densification Policy as "compatible residential and non-residential land uses" (*DP*, 2012: 6).

and sea views that define CCT's character. Furthermore, it states that this will not be a blanket policy CCT-wide, but rather be employed in strategic locations.

The Spatial Development Framework is set out in maps called District Plans, that apply the framework at a municipal, district and local level to help unlock and guide area specific development (I09,I10)(*MSDF*, 2017). Major drivers within the CCT are housing and transport, and therefore, the Primary Transport nodes are high interest areas (I04,I18) as well as the Urban Development Zones that are targeted nodes in which the property market is identified as underperforming versus the potential (I01,I18)(*IIP*, 2018).

Different methods are used by the CCT to incentivise the required development to achieve the vision of the Spatial Development Framework and these are laid out in the Investment Incentives Policy (*IIP*, 2018) (I01,I08,I18). In Urban Development Zones, an income tax rebate is applied to incentivize development of dense, mixed-use buildings and PBDM waive the stricter rules and assist in the application process (*IIP*, 2018)(I18). The Municipal Property Rates Act 6 of 2004 (*MPRA*, 2004) allows Valuations to incentivise types of developments by applying a density rates rebate to encourage owners to develop high density buildings (I01).

Section 5.2 The Technical System: Sharing and Managing the PMO

The CCT has over 27 000 employees in 50 departments and approximately 17 000 of those work on the network and GIS (I14)(Steenekamp, n.d.(a)). There are approximately 360 GIS professionals across the CCT working on the GIS platform (I04,I14)(Steenekamp, n.d.(b)). ESRI ArcGIS is the CCT enterprise software. GIS was introduced relatively early and the CCT has built up valuable expertise, resources and large data stores over time (I20,I23,I33).

All CCT systems are linked to the central GIS ("SAP", 2013), with the exception of the Government Revenue Management system (GRM), as the CCT has adopted the view that city management is inherently spatial (I22,I23,I36). The CCT GIS is integrated with an enterprise resource planning system known as Systems, Applications and Processes ("SAP", 2013) and a Development Application Management System (DAMS). DAMS and GRM are electronic workflow and data management tools used by Planning & Building Development Management (PBDM) and Valuations respectively. SAP, DAMS, GRM and the GIS integrate property records, the financial system and records management ("SAP", 2013; City of Cape Town, n.d.). An overview of the CCT technical system showing the various systems and their interactions is shown in Figure 5-2 and each system is discussed in the following subsections.[28]

5.2.1 SYSTEMS, APPLICATIONS AND PROCESSES (SAP)

SAP is the central property repository. The CCT adopted 420 SAP business processes ranging from property management to financial and human resources modules (I03)("SAP", 2013). Two modules, Land Use Management (SAP LUM) and Public Services Records Management (PSRM)(see Figure 5-2), are used for PBDM functions and integrate with the GIS, DAMS and GRM (I03,I35,I36,I37,I40)(Compion, 2015). SAP LUM holds all general property information, for example, ownership, property value and title deed information (I36,I40). There is a *Master geodatabase*, that is system-generated and synced with SAP LUM (I33). It is introduced in 5.3.2iii.

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[28] Refer to *Appendix C* for an in-depth diagram of the technical system.

PSRM holds all the PBDM case data; all documents lodged and used in PBDM applications (Compion, 2015). The management of property data in these data stores is discussed in 5.3.3. The data held in these modules is not spatially defined, and can be described as attribute information attached to each property via the unique erf key known as the LIS key. The LIS key is used throughout the CCT as a reference code. As shown in Figure 5-2, data flows between SAP LUM and GRM, and the GIS. This will be presented in 5.2.3 and 5.2.4 respectively.

5.2.2 DEVELOPMENT APPLICATION MANAGEMENT SYSTEM (DAMS)

DAMS facilitates the electronic submission of PBDM applications by the public through an online portal (I01,I03,I10,I26,I32)(Compion, 2015; City of Cape Town, n.d.). The public submit, track and manage their applications[29] online and the system is completely digital (I01,I03,I10,I26). CCT introduced DAMS as part of its paperless drive and to lessen the dependency on a public-facing counter service (I10,I32).

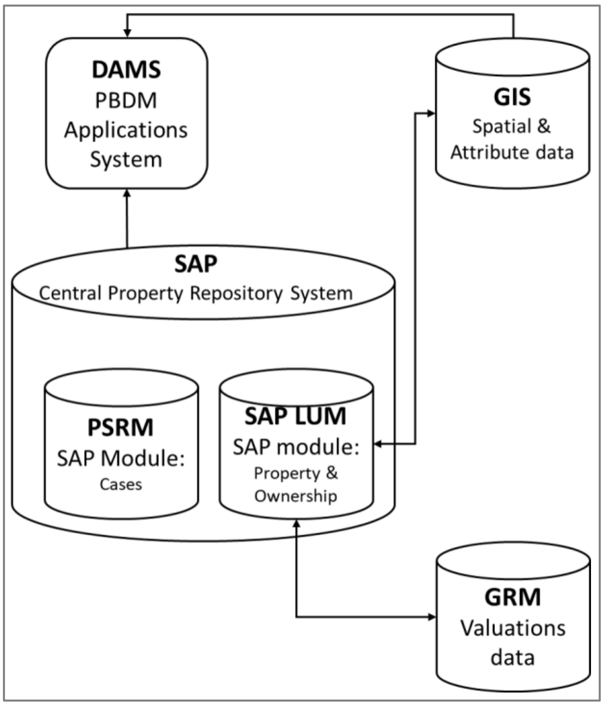

Figure 5-2 An overview of the CCT technical system and the data stores that contribute to and hold property data and their interactions (I04,I14,I30,I33,I35,I36,I37)(Steenekamp, n.d.(b); Compion, 2015).

DAMS is a platform that integrates[30] the necessary property data for Property Value Chain use, supporting the land use and development functions (I10)(Compion, 2015). DAMS allows a single record for every property to be accessed inter-departmentally by integrating with SAP and the GIS (Compion, 2015; "LUM Process", n.d.). DAMS uses the unique LIS key to pull property information from SAP LUM, application case data from PSRM, and maps and spatial property information from the GIS as shown in Figure 5-2 (I14,I33,I36)(Compion, 2015).

Using DAMS, the staff electronically process and circulate submissions with ease through the relevant departments (I01,I03)(Compion, 2015; City of Cape Town, n.d.). DAMS was introduced with the aim of standardising PBDM processes and thereby improving transparency and service delivery (I10,I32)(City of Cape Town, n.d.).

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[29] All application data is held is SAP PSRM (see 5.2.1).

[30] DAMS does not store data within itself. It is a platform for connecting data stores.

5.2.3 GOVERNMENT REVENUE MANAGEMENT SYSTEM

The Government Revenue Management system (GRM) is the self-contained system used by Valuations to streamline workflows, data capture and data management (I34,I37) and is independent of SAP and the GIS (I35,I36). GRM supports the land administration function, land value. GRM holds a detailed relational database on CCT properties (I23), information that is captured by Valuations through field and in-office surveys (I35)(see 5.3.4). The data held in GRM could be highly useful to other departments (I20,I23). However, only selected valuations datasets are shared via GIS and SAP (I20,I22,I36) and in a simplified form. Therefore, valuable information is removed (I23). As shown in Figure 5-2, GRM interfaces with SAP LUM to access property data compiled by other Property Value Chain agents to update the GRM records (I35,I36,I37). Furthermore, GRM updates the property value in SAP LUM; this is used by the Revenue department for property taxation (I36). It should be noted that, like SAP LUM, GRM does not hold spatially-defined property information (I23).

5.2.4 THE CCT GIS: THE PRODUCTION AND REPORTING ENVIRONMENTS

The GIS is home to the CCT's spatial data, and therefore, the Property Management Object (PMO). The smallest entity of the GIS is the erf with a unique identifier, the LIS key (I04). The attribute data associated with spatial objects, for example, zone information, is held in the GIS (I33). The GIS and SAP LUM sync to exchange property information as shown in Figure 5-2 and is discussed in 5.3.2.

Corporate GIS, a division of Information and Knowledge Management, manages a centralized record of shared datasets, the *Reporting geodatabase*, and the dissemination of those datasets (I01,I14,I22). The *Reporting geodatabase* is made up of the shared datasets that all GIS staff can access (I01,I14)(Steenekamp, n.d.(b)). Figure 5-3 illustrates the GIS datasets lifecycle, from production to sharing.

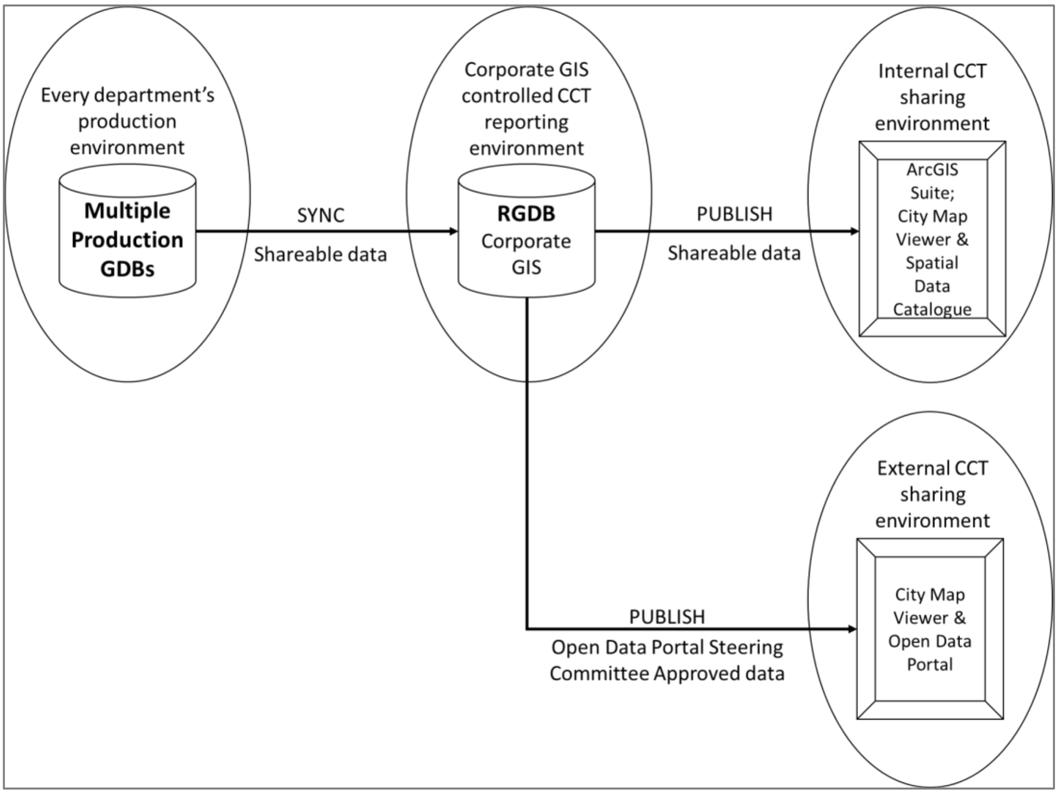

Figure 5-3 Data flow from a production to the reporting environment via the *Reporting geodatabase* (RGDB) for sharing internally and externally (Steenekamp, n.d.(b))(I14,I33,I40).

Every department with a GIS section has its own production geodatabase within the so-called production environment (see Figure 5-3)(Steenekamp, n.d.(b)). Selected layers from each production geodatabase are synced with the *Reporting geodatabase* (see Figure 5-3). There are 365 shared datasets and each layer has a custodian. It follows that there are 365 custodians throughout the CCT that are responsible for the production and maintenance of data (I14). For example, PBDM are the custodians of the cadastral and land use GIS layers (I01,I09,I10,I17). It is seen as important that each layer is created and managed by a person with specialized knowledge and understanding of the dataset (I04). A custodian is typically a Professional Officer with GIS proficiency (Steenekamp, n.d.(b)). It is their responsibility to ensure the datasets are up-to-date and of the highest quality (I04,I14).

The production and reporting environments are kept separate (see Figure 5-3). This offers a safety mechanism; the original dataset cannot be corrupted in the reporting environment (I14). Corporate GIS have a copy of each of the shared datasets on the *Reporting geodatabase* and should ensure sharing of these is in line with adopted standards (I04;I14;I22). The CCT Spatial Data Management Framework (*SDMF*, 2017) sets out standards to control that creation, use and management of the GIS datasets, as informed by national legislation and international standards (I14). Only data that conforms to these standards is shared to ensure the consistency and compatibility of CCT datasets (I14)(*SDMF*, 2017; Steenekamp, n.d.(b)).

Typically, Corporate GIS update the *Reporting geodatabase* datasets on a daily basis, unless the custodian has set a different update period (I14). Thus, the datasets should always be up-to-date and relevant. However, this has not been found to hold true and at times it is not clear when the last update to a dataset was performed because the metadata is incomplete or missing (I50).

Furthermore, the datasets on the *Reporting geodatabase* are the only source of all shared geospatial data, even though there are multiple ways to access the shared datasets (see Figure 5-3 and the following sections)(I14). In other words, there is one identifiable custodian, data source and data flow for each dataset within the reporting environment (Steenekamp, n.d.(b)). There is no unnecessary extraction or duplication of published data because it is recognised as important for the GIS to have a strong, stable and unique core (I14).

5.2.5 SHARING DATA INTERNALLY WITHIN THE CCT

To share GIS data within the CCT, Corporate GIS maintain three data-access points (see Figure 5-3). Firstly, the *Reporting geodatabase* is accessible by all CCT GIS users from within the ArcGIS software suite (I14,I15). Non-GIS staff can access the shared datasets via two other options, City Map Viewer and Spatial Data Catalogue. The City Map Viewer is an online 2D GIS platform served via ESRI Portal and accessible via any internet browser (I14,I15). All 365 *Reporting geodatabase*' layers can be viewed and analysed in this viewer and SAP LUM property data[31] is pulled directly into the viewer, enriching the experience (see Figure 5-2)(I14)(Compion, 2015). The Spatial Data Catalogue is a web-based library of the *Reporting geodatabase* layers and these are downloadable in various formats.

5.2.6 SHARING DATA EXTERNALLY WITH THE PUBLIC

The CCT adopted an Open Data Policy (*ODP*, 2014) that allows any person to request data in its raw format, on approval of the Open Data Portal Steering Committee (I03). All datasets that are publicly available have to go

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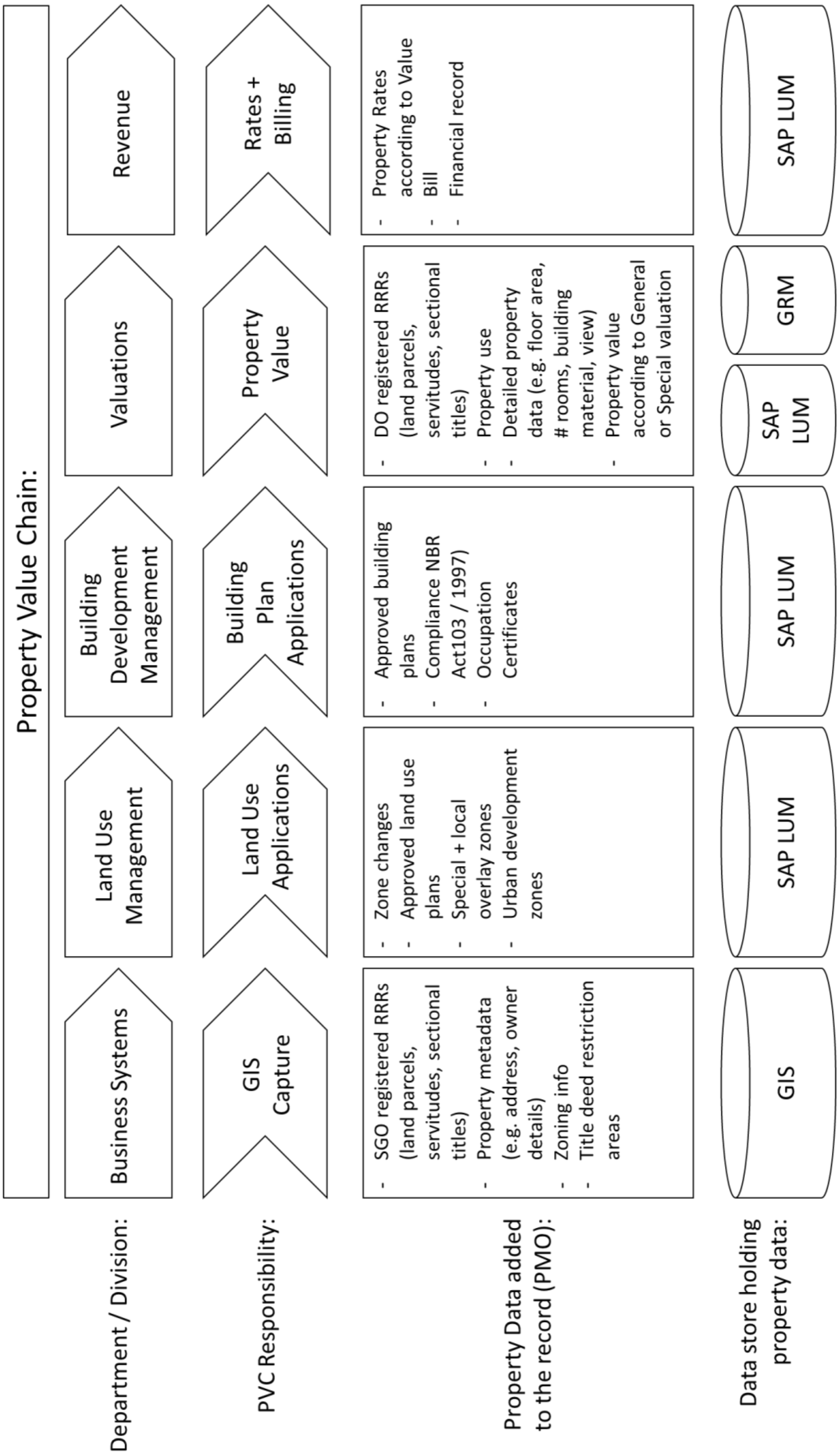
[31] Refer to 5.3.2 and 5.3.3.

through an approval process before publication (*ODP*, 2014). This committee acts as a control mechanism to check compliance with legislation and standards (I04,I14). Confidential information is removed from all externally shared layers in terms of the Open Data Policy (*ODP*, 2014; Steenekamp, n.d.(b)).

There is an external City Map Viewer, a simplified version of the internal viewer, and an external data library, the Open Data Portal, that are publically accessible (see Figure 5-3). The datasets are pulled directly from the *Reporting geodatabase* to avoid duplication of data. The viewer and library provide the public with free access to datasets like zoning rights, street addresses and survey diagrams (I04,I14,I26,I27). It is noted that it is a simple, web-based platform that could be improved (I03). Furthermore, there is a public office, City Maps, that distributes data to the public on request (I04). These platforms assist in establishing better information sharing between the CCT and the public (I14). This is in line with CCT management's aim to increase available information to create a more informed and involved public (I08,I14) and the Open Data Policy (*ODP*, 2014).

Section 5.3 The PMO: The Creation, Use and Management of Property Information within the CCT Property Management System



	Property Value Chain:				
Department / Division:	Business Systems	Land Use Management	Building Development Management	Valuations	Revenue
PVC Responsibility:	GIS Capture	Land Use Applications	Building Plan Applications	Property Value	Rates + Billing
Property Data added to the record (PMO):	- SGO registered RRRs (land parcels, servitudes, sectional titles) - Property metadata (e.g. address, owner details) - Zoning info - Title deed restriction areas	- Zone changes - Approved land use plans - Special + local overlay zones - Urban development zones	- Approved building plans - Compliance NBR Act103 / 1997) - Occupation Certificates	- DO registered RRRs (land parcels, servitudes, sectional titles) - Property use - Detailed property data (e.g. floor area, # rooms, building material, view) - Property value according to General or Special valuation	- Property Rates according to Value - Bill - Financial record
Data store holding property data:	GIS	SAP LUM	SAP LUM	SAP LUM GRM	SAP LUM

Figure 5-4 The creation, storage & maintenance of property data (the PMO) by Property Value Chain agents

5.3.1 INTRODUCING THE PROPERTY VALUE CHAIN

As stated, the departments that generate property-specific information and therefore contribute to the Property Management Object (PMO), make up the Property Value Chain (bar one, the Geospatial division). Each department within the Property Value Chain adds information to the PMO, for example, the erf, the existing building, value and land use (I22)(City of Cape Town, 2011). Each role player in the Property Management System (PMS) is known as an agent according to the adopted Business Process Modelling definitions (see 3.4.2).

The Property Value Chain is completely digital (I10) with adequate 2D systems in place for data capture and analysis. The process can be summarised as follows and is shown in a flow diagram, Figure 5-4 (I18,I22)(City of Cape Town, 2011):

i. Business Systems build the initial property information record,
ii. Land Use Management make changes related to land use approvals,
iii. Building Development Management make changes related to development approvals,
iv. Valuations value each property in the CCT and,
v. Revenue finalise the property rates to be paid.

However, this is a simplistic representation of the complex PMS that builds the PMO.

Therefore, a data flow diagram (DFD), Figure 5-5, as adopted in Chapter 4, has been used to map the flow of property data within the PMS. The diagram is a product of the analysis and combination of the data collected via interviews, documentary evidence (including organisation structures, workflows and policies) and personal work experiences (see 4.3.1). By using data flow as the focus of the model, one gains an understanding of the use and management of the PMO while introducing the agents that interact with the data. For the sake of simplification and increased understanding, the complex primary diagram is split into logical parts, each dealing with a section of the PMO creation and editing. Each part forms a part of the whole and, in reality, cannot be separated out of the system.

Each smaller diagram is coloured to illustrate how it is broken up and is shown as a smaller DFD and discussed in the appropriate subsection. Initially, 5.3.2 (blue) introduces the incorporation of the real RRRs (LPO) layer of the PMO by both Business Systems and Valuations. The data flow begins at both the Surveyor General's Office and the Deeds Office. Secondly, 5.3.3 (yellow) shows the Planning & Building Development Management (PBDM) data flows starting with the public application submission and ending with the updating of the PMO records with approved land use or development plans. Finally, 5.3.4 (orange) presents the Valuations and Revenue processes that contribute to the PMO.

In Figure 5-5, one should note that each data flow ends at the *Share Datasets* process (bottom right). As discussed in 5.2.4, every department shares selected datasets from their production environment to the reporting environment via the GIS. These are published internally and externally after a quality control process (I04)(see 5.2.4).

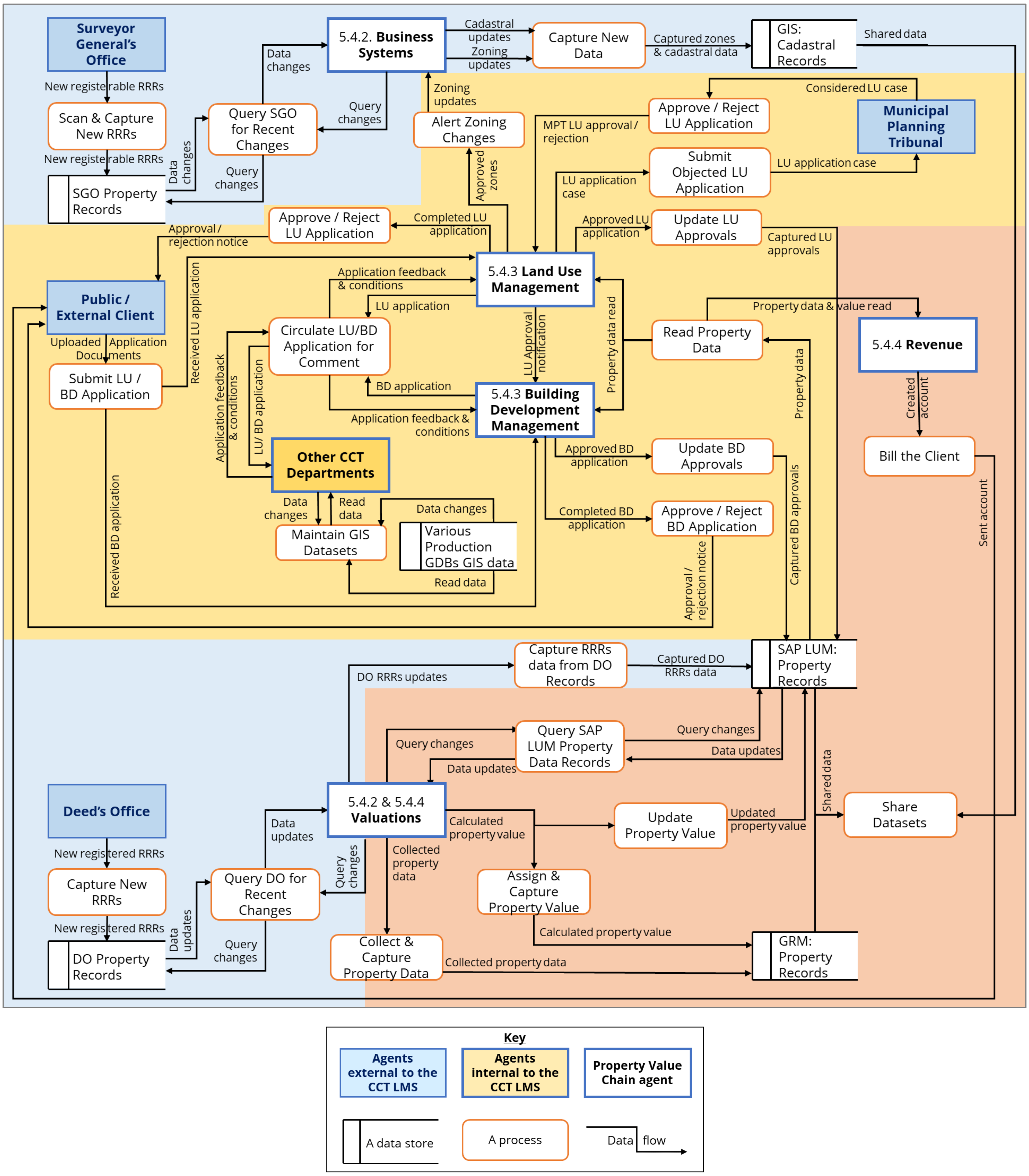


Figure 5-5 The flow of property data within the CCT PMS using a data flow diagram

5.3.2 DEFINING THE PMO: THE REAL PROPERTY RIGHTS DATA

The Business Systems and Valuations departments capture the spatial and non-spatial data associated with real RRRs, inherited from the Surveyor General's Office and Deeds Office (I30,I36). This section refers to Figure 5-6, the first part of the parent diagram, Figure 5-5. This is the first step in the Property Value Chain (I32) and in building the Property Management Object (PMO)(see Figure 6-1). GIS Professionals are the custodians of these datasets and are responsible for capturing real rights additions and changes (I06,I31,I33). These custodians are neither Professional Land Surveyors nor Conveyancers and do not have experience in property law (I33).

The cadastral base layer of the PMO is made up of the real property rights as approved in the Surveyor General's Office and/or registered in the Deeds Office, shown as agents external to the PMS in Figure 5-6. The CCT has an informal working relationship with the Surveyor General's Office (I30) but not with the Deeds Office (I36). There are two streams of data capture. Firstly, Business Systems captures the diagrammatic (spatial) data of approved Surveyor General's Office properties into the GIS, and secondly, Valuations captures the deed (non-spatial) information of Deeds Office registered properties into SAP LUM (I30,I36). It should be noted that Valuations and Business Systems do not have a working relationship (I30,I36) even though both are recording real RRRs that define property extent, location and use.

i BUSINESS SYSTEMS: SURVEYOR GENERAL'S OFFICE PROPERTY DATA AND DEVELOPMENT RIGHTS

As shown in Figure 5-6, newly approved cadastral records are scanned and captured by the Surveyor General's Office into the Surveyor General's Office Property Records data store (I50). As stated, the Surveyor General's Office is responsible for the SA cadastre. However, the GIS that they maintain is of an unreliable standard (I05,I14,I33,I50). Additionally, the Surveyor General's Office datasets are shapefiles and therefore lack the intelligence required by the CCT (I14,I50). It is imperative that the cadastral layer is of the highest possible standard because it forms the core of the CCT GIS (I14).

The Business Systems' custodian of the real RRRs data is alerted to property boundary changes by manually querying the Surveyor General's Office data store (see Figure 5-6). Additionally, other CCT agents notify the custodian of new, changed or erroneous cadastral records on an *ad hoc* basis (I30,I31). The custodian downloads the new records which are then validated before being captured manually into the GIS (see Figure 5-6)(I30). The geometry and any attribute data associated with the property is recorded in the GIS and assigned to that property's LIS key.

The coordinated location, extent and attributes of newly approved properties are captured directly off the scanned hardcopies of registered Surveyor General's Office diagrams rather than adopting the Surveyor General's Office digital records (I14). This is ascribed to the unreliable standard of the Surveyor General's Office GIS (I05,I14). All properties and real RRRs are captured in 2D into separate feature classes in the *Working geodatabase* in the Business Systems' production environment. This includes freehold ownership, sectional title, and limited real rights such as servitudes and registerable leases (I30,I31,I36,I40). The *Working geodatabase* is the production geodatabase of Business Systems and is continuously maintained and updated (I30).

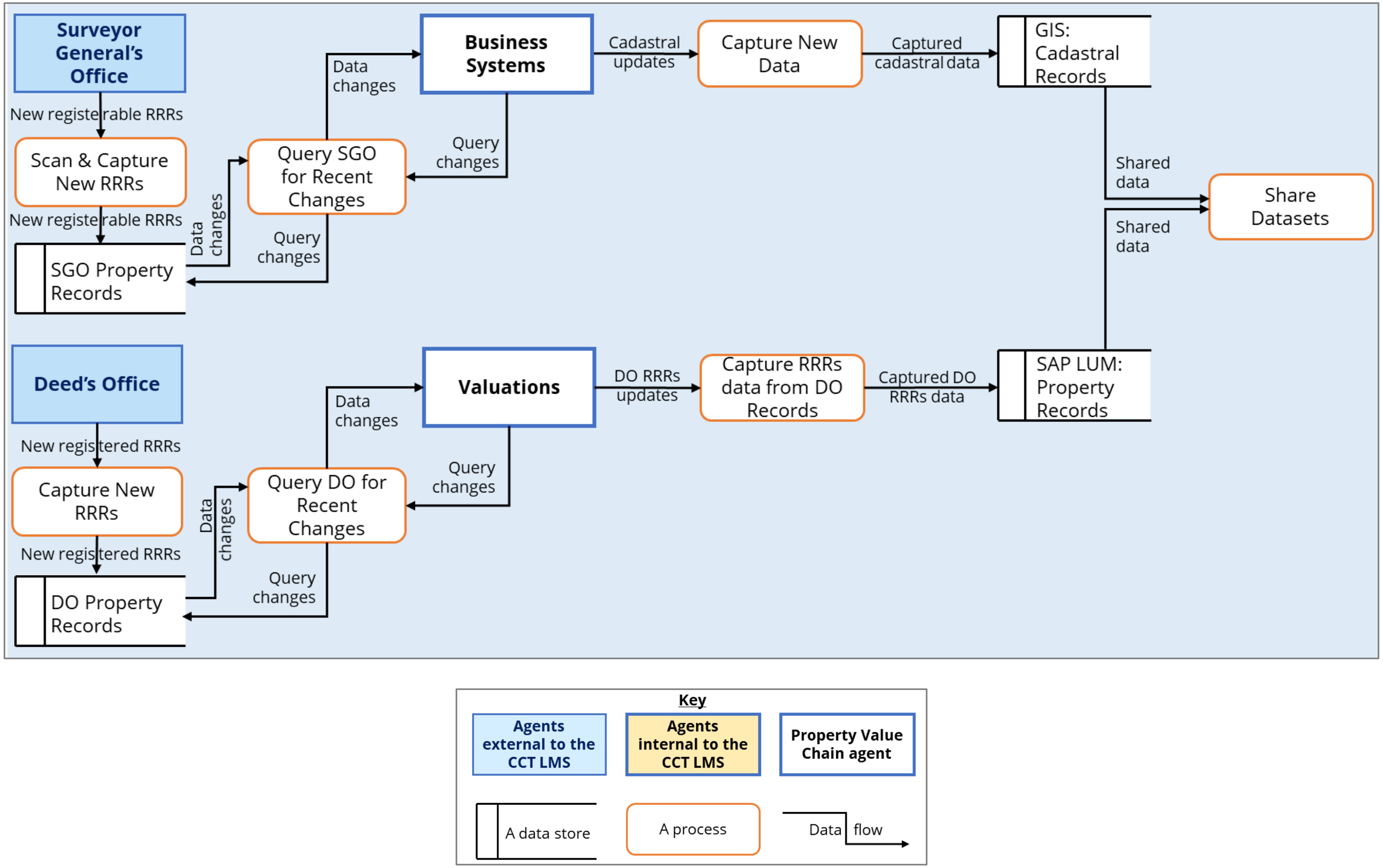


Figure 5-6 The flow of real property RRRs data into and within the CCT PMS (Part 1 of the parent diagram, Figure 5-5)

Sectional title records are captured by Business Systems into a feature class to a floor level of detail. The floor level is not an absolute height value, but rather a ceiling height value (I33). Furthermore, the heights bounding real rights, for example a servitude with a bounded vertical extent, are not captured (I04,I20,I30,I31,I50). Therefore, the height implications of these real rights are ignored. This has resulted in a number of unforeseen consequences for the CCT[32] (I20). There is no plan to introduce this functionality as yet because it requires an overhaul of the database schema (I30).

ii VALUATIONS: DEEDS OFFICE PROPERTY DATA

The Deeds Office registers title deeds that capture new and transferred RRRs into the Deeds Office Property Records data store (see Figure 5-6). Valuations has a Deeds Office account that is checked daily for new or amended records (I30,I36). Each title deed is downloaded and then manually uploaded to SAP LUM by Valuations. SAP LUM automatically extracts data from each uploaded document. A responsible team monitors this process (I36). The title deed data is captured in a textual (non-spatial) format, including any coordinate data (I30,I36). Servitudes are not captured and therefore only those created on Surveyor General's Office diagrams will be recorded in the PMS. There is discussion that the Deeds Office will notify Valuations of newly registered servitudes in the near future; this will improve the completeness of the CCT records (I22).

iii NOTES ON THE LAND PARCEL DATASET

The current primary base layer of the GIS and the conceptual PMO is the land parcel feature class that captures all CCT erven. Every erf in this feature class has a unique identifier, the LIS key, along with a Surveyor General's Office code, an erf number and an allotment area (I04,I36). All other property data is linked to the LIS key, including land use (I01,I04,I09). This dataset is a core base layer on which many CCT departments function (I22,I30) and it is shared internally and externally (see Section 5.2).

The land parcel dataset is captured by Business Systems into the *Working geodatabase* (I30). All changes are captured into this geodatabase such that the neighbouring erven are updated to snap to the latest coordinated boundary beacons. Therefore, there should be no slivers within this cadastral layer and it is topologically correct to 5cm (I30,I33).

However, the *Working geodatabase* is multi-versioned, as it is worked on continuously by multiple users. This makes it unsuitable as a reference database for shared datasets. Therefore, the custodian runs daily onramps of the land parcel layer from the *Working geodatabase* onto SAP LUM and the *Master geodatabase* in the form of a JavaScript Object Notation (JSON) message, causing the geometry to be translated into text data (I30,I33). Recall, the *Master geodatabase* is system-generated and is in-sync with SAP LUM and there are no topological quality control mechanisms on this geodatabase. Therefore, topological errors can occur in the *Master geodatabase*' datasets, including in the land parcel layer (I33).

The *Master geodatabase* is then synced with the *Reporting geodatabase* and shared. Therefore, the shared land parcel dataset is not topologically clean (I33). There are slivers and overlaps visible in this 2D dataset (I50). If topological

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[32] See Blouberg Beach Road in *Appendix D* as an example.

errors are identified in the *Reporting geodatabase* dataset, the custodian does a forced manual update of that block of erven from the *Working geodatabase* onto the *Master geodatabase* and SAP LUM (I30).

5.3.3 DEFINING THE PMO: PLANNING & BUILDING DEVELOPMENT MANAGEMENT DATA

Planning & Building Development Management (PBDM) collect information during the applications processes and update property records as and when changes are approved (I17). The PBDM records are erf-based and tied to the LIS key. The datasets are held in SAP LUM and are accessed via the DAMS platform (see 5.2.2, Figure 5-2)(I32).

i THE PROPERTY VALUE CHAIN: LAND USE & PROPERTY DEVELOPMENT DATA FLOWS

Land Use Management (LUM) handle applications in terms of the Development Management Scheme (see 5.4.3.ii)(*DMS*, 2015), for example, maximum height departures or land use changes (I1, I9,I10)(Koekemoer, 2017). Building Development Management (BDM) assess and approve development applications and conduct follow-up inspections to verify if the development complies with the approved plans (I32). Additionally, BDM are responsible for ensuring any development is in compliance with section 7 of the National Building Regulations and Standards Act 103 of 1977 (*NBR*, 1977)(I32)(Koekemoer, 2017). The two PBDM processes follow similar steps, as shown in Figure 5-7.

Initially, an external client will submit a land use or development application via DAMS and it is directed to either LUM or BDM (see Figure 5-7). A land use application is only necessary if the proposed development falls outside the development envelope as defined by the DMS (see 5.4.3.ii)(I01,I09,I10). Otherwise, only a building plan approval is necessary. LUM and BDM should assess the context and impact of each proposal submitted in relation to CCT policies and relevant legislation (Koekemoer, 2018; “LUM Process”, n.d.) (I01,I09,I10). As stated above, DAMS pulls property data from both SAP LUM and the GIS (see Figure 5-2) to provide holistic information on an erf to the decision-makers (Compion, 2015).

As shown in Figure 5-7, each application, whether land use or development, is circulated to numerous relevant CCT departments through DAMS. Each department will check compliance and provide feedback and any necessary conditions to approval with regards to their focus areas (I11,I32). Every department will compare the application to their production geodatabase datasets to inform their feedback and make any updates to that geodatabase as necessary. Additionally, they can use DAMS to pull in the GIS datasets for further information.

LUM apply concessions or departures to approved applications to achieve the Spatial Development Framework goals (I19). A land use approval may include development conditions that will be passed on to BDM in the approval notification (see Figure 5-7) that must be accounted for when a development proposal is submitted (I32). The public may object to a land use application, and if any objections are received, the case is prepared by LUM and then referred to the Municipal Planning Tribunal for decision-making (see Figure 5-7).

The Municipal Planning Tribunal is a body that is made up of various private built environment professionals that meet on a monthly basis to address the larger, more complex and often controversial applications (I03). The challenge for the Tribunal is that there is often a large amount of paperwork accompanying numerous cases and little time to familiarize themselves with each case before a decision is made (I08,I11). Furthermore, the Tribunal do not have access to the detailed property records that CCT employees do and have to rely on the information they are given (I08). The land use application process does include an appeals process if the public are not satisfied with the outcome of the application. All approved land use applications are recorded into SAP LUM, updating the property record, and BDM is notified thereof (see Figure 5-7).

Land Use Management (LUM) is responsible for the definition of and changes to the zone of every erf in terms of the DMS (see 5.4.3.ii). Each zone has a defined set of rules that regulate development and land use for all CCT erven. However, Business Systems is the custodian of this layer and therefore, LUM notifies Business Systems of any changes that need to be made to the zone dataset (see Figure 5-7). This dataset is captured by Business Systems into the GIS as a coded domain and it is linked to each erf using the LIS key (I32,I33). In other words, it is a numerical value that can be queried and shared easily (I30,I33).

A Building Development Management (BDM) application often follows a land use approval, but not always. As mentioned, if the proposal falls within the development envelope, the land use application is nullified (I01,I09,I10). The initial step in the BDM process is to check LUM compliance and there is a pre-consultation process in which any land use approvals are reviewed (I32). Following this the client then submits building plans to PBDM. A large portion of the development approval process involves section 7 of the National Building Regulations Act (1977). This section is highly controversial because of its subjective application (I32)(Ogle, 2017). It is concerned with evaluating whether a proposed development will be unsightly, disfigure the area or decrease the value of the surrounding properties (Ogle, 2017). If so, the proposed development is unlikely to be approved.

The Building Controls Officer does the final compliance check and recommends a decision to the CCT council[33], who then sign it off. If approved, construction can begin. All approved BDM applications are recorded into SAP LUM, updating the property record (see Figure 5-7). Once the building is complete, it is checked by a building inspector, a BDM representative, and certified for occupation. BDM then marks this property as ready for Valuations assessment in SAP LUM (I32)(Koekemoer, 2018).

In contrast to the LUM process, there is no appeals authority in the BDM process that an applicant can turn to. Additionally, outside parties cannot appeal against development plans after they have been approved by LUM (I32). In other words, the public have to be well-informed during the land use application process, because it is too late for them to object once the application reaches the stage of development applications. Alternatively, if a building falls within the allowable development envelope and no land use application is necessary, the only option for members of the public is to resort to the courts to appeal the development proposed (I32).

ii LAND USE PROPERTY DATA: THE DEVELOPMENT MANAGEMENT SCHEME

The Development Management Scheme (*DMS*, 2015) defines the maximum use and development potential of every erf in the CCT (I23). Each erf is assigned a zone that sets out the rules that are applied to that erf. The rules set out development restrictions on building setbacks and height, and thereby define a volume in which a person may develop their property. This volume is known as the development envelope and it is not a registerable right, but is rather a restriction on ownership upheld by the local authority. Furthermore, the rules set out the allowable land uses for that zone.

The development envelope can be defined as the 3D space that is delineated by the rules of the DMS for each property in the CCT. It is originated from the erf and the zone allocated to that parcel. The envelope is formed by

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[33] The council consists of the elected officials that represent the public at local government level.

the setback lines, the maximum building height, the allowable floor factor of that zone and any title deed conditions that may determine the shape of the allowable development volume. These are directly related to the parcel shape and area, the cadastral boundaries, the road centreline and kerb position, and the existing ground level of that erf (*DMS*, 2015). The development envelope forms an important part of the Property Management Object (PMO)(see Figure 6-1) because it puts restrictions on the possible use of that PMO.

The development envelope is complicated by the various definitions of 'existing ground level' [34] (I08,I11,I26). These definitions are flexible in their wording and therefore the developer may choose to apply the definitions strategically to suit their purpose (I04,I06,I08,I11,I26). This can cause conflict between different parties and it becomes difficult to accurately model the development envelope height for planning purposes (I50).

Additionally, road centrelines, that determine horizontal setback lines for some zones, are calculated from the cadastral boundaries by the CCT and are not mapped on the physical road's centreline. Therefore, this line can be off-centre. A kerbline dataset could more accurately determine the road centreline (I05). It is CCT's responsibility to maintain data on the kerblines and road levels (I32), but these datasets do not currently exist (I04). Each of these datasets would add information to the PMO, because they directly influence the shape of the development envelope (I05).

The DMS includes special overlay zones to allow for specific rules to be applied to selected areas for the purpose of protecting culture or natural heritage, or promoting a certain type of development (I01,I09,I10). There are a number of smaller, additional policies used by Land Use Management (LUM) to manage more complex applications. In terms of the DMS, the highest a building may be built is 60m (*DMS*, 2015). Any land use applications over this height are governed by the Tall Buildings Policy (*TBP*, 2013) and automatically require a departure through a land use application (I09). These policies can be area specific. For example, the Scenic Drive Management Plan (*SDMP*, 2003) was introduced to protect the views of CCT from various scenic routes that are identified within the DMS.

Furthermore, the DMS supports both underground and air rights creation to allow for the development of below and above ground structures (*SBP*, 2012)(I03). Underground parking garages and overhead sky bridges are becoming common. The CCT introduced the Sky Bridge Policy (2012) to provide guidelines on the where, when and how these types of constructions are approved. This policy was introduced in reaction to the complexity and expense associated with these structures (I03).

To conclude, the DMS creates and manages various elements that add to the information tied to a property, and therefore, the PMO.

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[34] See *Appendix C* for the relevant Development Management Scheme (DMS) definitions.

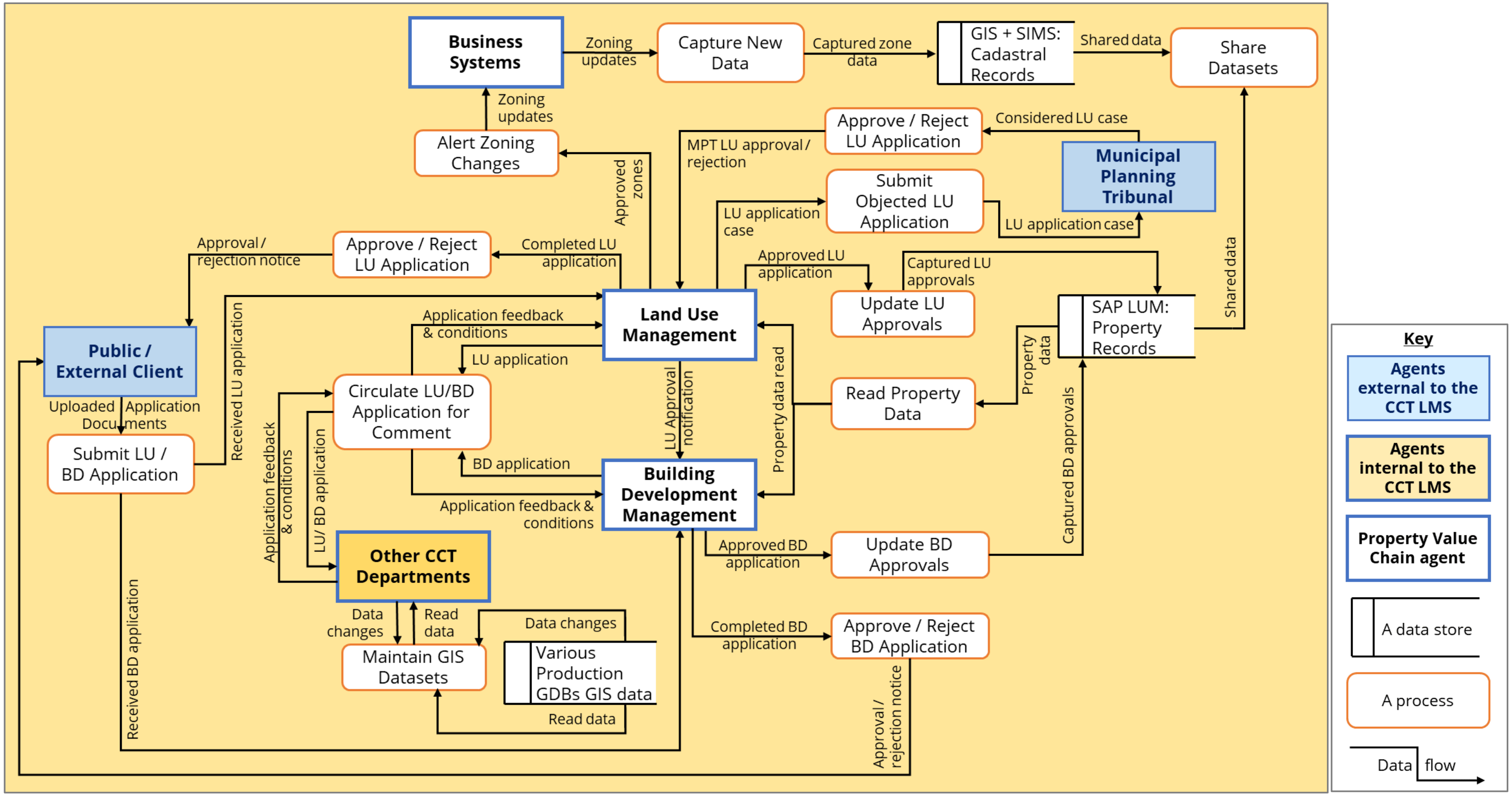

Figure 5-7 The flow of land use and development property information within the CCT PMS (Part 2 of the parent diagram, Figure 5-5

iii THE BUILDING DEVELOPMENT DATA

A development application consists of a site plan and layout drawings, including individual floor plans and 'as built' plans (I32)(Koekemoer, 2017). All plans are scanned and submitted via DAMS in 2D. The applicant supplies all the information relevant to the application and the building plans hold the spatial information (I01,I09,I10,I32). Building Development Management (BDM) accesses any additional information needed via DAMS and does not generate any spatial data of the proposed developments (I32). If approved, the plans are stored in SAP LUM, tied to that erf via the LIS key, thus adding information to the PMO (see Figure 6-1).

5.3.4 DEFINING THE PMO: THE VALUATIONS AND REVENUE DATASETS

In SA, real property ownership is taxed at a municipal level.[35] A large portion of municipal budget relies on this income and therefore, local governments are heavily invested in property taxation (McGaffin *et al.*, 2016)(I18). The CCT departments responsible for land valuation and taxation are Valuations and Revenue, respectively. The Valuations section collects property data and inherits data from Business Systems and Planning & Building Development Management (PBDM)(I18), including land use and cadastral information, via SAP LUM (I17,I36). Refer to Figure 5-8 below for the flow of property data in the Valuations and Revenue processes. [36]

i THE PROCESS OF VALUATION

Valuers conduct traditional valuations consisting of firstly, general valuations and secondly, supplementary valuations of new developments (I17,I35). Any new developments are highlighted by the PBDM approvals (I17) and can be a change in land use type or a new or amended building.

Additionally, the Municipal Property Rates Act (2004) allows for mass appraisals of property (I17). Computer Assisted Mass Appraisal is used to value properties *en masse* by employing a least squares methodology that combines the variables that influence a property's value and the sales prices in that area. This method is then used, along with specific property data (such as number of bathrooms (I17,I36)) to calculate a market value for that property (I01,I17,I20,I35). The specific property data is sourced from field inspections and in-office surveys (I35,I36).

Field valuation surveys are the most accurate method of evaluating a property (I17,I22). Various aspects of the property are assessed and the land use is verified (I17). This method is especially important for complex and high value properties where modelling is unlikely to yield a defensible market value estimate (I22). However, access is often an issue and this method is resource hungry and expensive (I17). The cost effectiveness of data collection methods is an important deciding factor on how to evaluate properties (I22).

In-office inspections using high resolution oblique photography (I05) is used as a complementary tool to field surveys or as a stand-alone tool in the process of determining the market value of a property (I22). The software allows measurements with an accuracy of 0.1m and can be used to determine floor space, building area, height, and to identify illegal buildings (I05). This method makes use of the building plans to confirm the data collected (I22).

ii VALUATIONS DATA

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[35] It is independent of national government and, therefore, critical for maintaining local government democracy.

[36] The capture of real RRRs from the Deeds Office records (see 5.3.2ii) is repeated in this diagram for continuity sake.

A property's market value is determined by assessing explicit predefined characteristics. Valuations data is held in the Government Revenue Management system (GRM)(see 5.2.3) and is tied to the erf using the LIS key (I36,I37). As stated, the Deeds Office RRRs are captured by Valuations into SAP LUM (see Figure 5-8). Property information compiled by PBDM and Business Systems is inherited by pulling that data from SAP LUM into GRM (see Figure 5-8)(I36). This is a manual process to update the GRM property record with any erf or land use changes and any approved building plans.

Data collected via field and in-office surveys is captured directly into GRM (see Figure 5-8), is attributed to a specific property and is not spatially defined (I22,I23). This data adds information to the Property Management Object (PMO) record (see Figure 6-1). The information is collected remotely using the building plans and the oblique viewer or in the field using a detailed data collection form[37] (I20,I34,I35). The form dictates specific value-adding property information that the evaluator must record including, but not limited to, the building condition and materials, floor area, the number of rooms, access and security, the neighbourhood character, environmental noise, topography, views and, importantly, the use of the property (I20,I22,I36).

In terms of the Municipal Property Rates Act (2004), the land use must inform the tax paid by the property owner. The potential land use and development of a property has a large impact on the value (I10,I22). This data is inherited from PBDM via SAP LUM (I17) but Valuations performs checks and adds building and land use information into GRM according to their own development and land use definitions (I22). These definitions do not align with the DMS definitions used by PBDM (I23). Valuations records land use data per floor of a building and in a measure of square metres (I01,I23). This is a higher LOD than the land use recorded by PBDM (I23).

In the valuations process and specifically in the CCT, the view and relative security of a property are important attributes of property value. A property will be graded according to the quality of the view and by the apparent security (a flat above ground level is seen as more secure)(I17,I18,I22). In CCT, the public ascribe high value to a good view as indicated in higher market values, especially in upmarket areas (I22). Unfortunately, a view is not a legal right and is not protected in law.

As stated above, Computer Assisted Mass Appraisals combine all the data collected and a market value is calculated for that property in GRM (see Figure 5-8)(I17,I18,I20,I22,I36). Additionally, Valuations update the market values of the properties in SAP LUM (see Figure 5-8)(I36). Following this, Revenue make use of the market value recorded in SAP LUM to generate the amount of property tax that is added to the client's account for billing (I18)(see Figure 5-8).

It must be reinforced that the information stored by Valuations is not spatially reference. All valuations data is recorded as attributes attached to an erf, building or floor identifier (I22,I36).

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[37] The data collection form is deemed confidential by the CCT and therefore cannot be shared as part of this research.

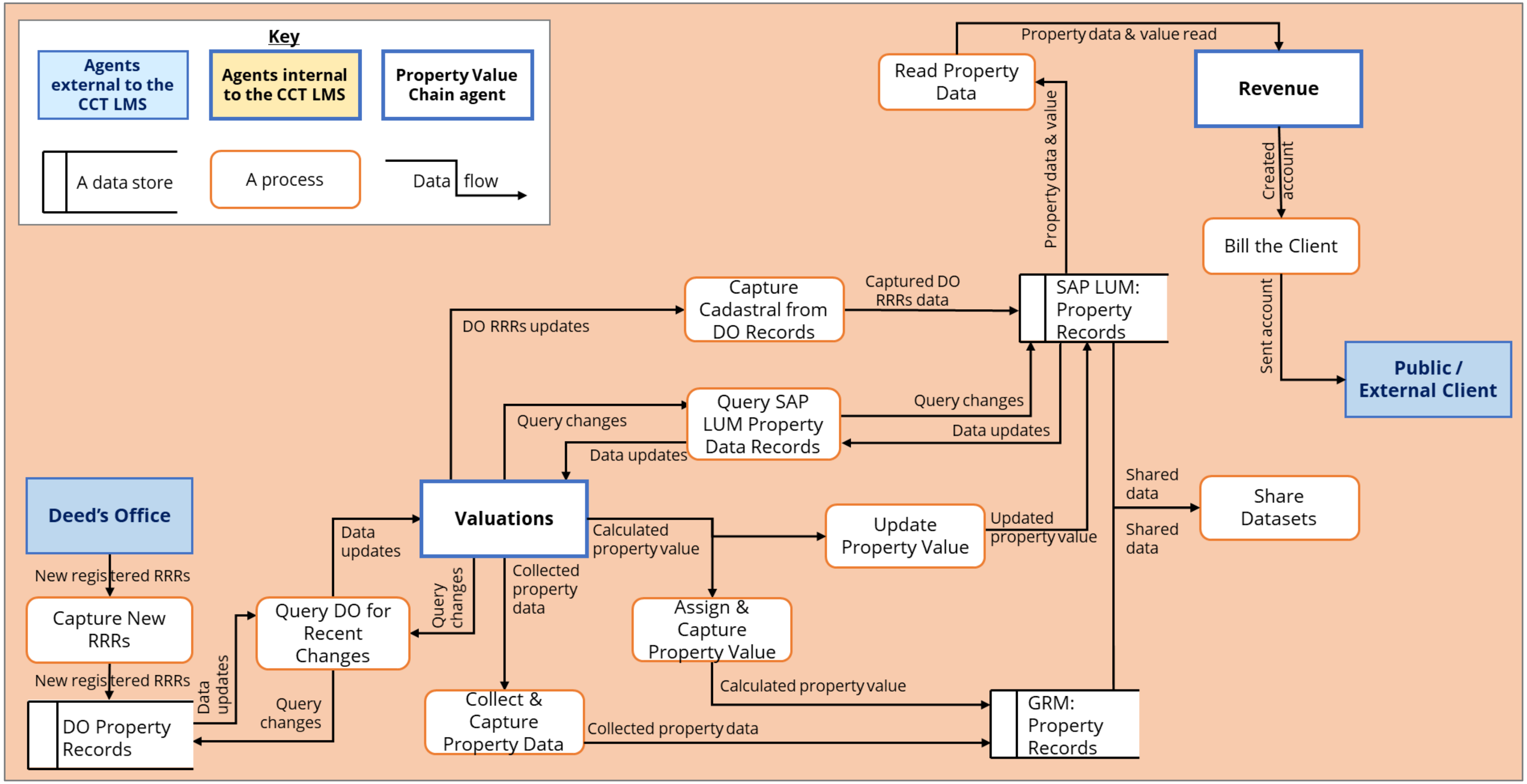

Figure 5-8 The flow of valuations property information within the CCT PMS (Part 3 of the parent diagram, Figure 5-5)

5.3.5 DEFINING THE PMO: THE BASE DATA LAYERS

The Information & Knowledge Management Geospatial division is an agent internal to CCT PMS (see Figure 5-9). This division is the custodian of the GIS geospatial base layers (I04,I05). These layers include the aerial photography (orthometric and oblique's), digital terrain models (DTMs)[38] and terrain contours (I04,I05,I06,I14). Additionally, this division captures 3D building models (see 6.1.1i). A final copy of the geospatial datasets are kept in the production environment geodatabase named CGIS (see Figure 5-9). These datasets are published to the internal and external viewers via the *Reporting geodatabase* (see 5.2.4)(I04).

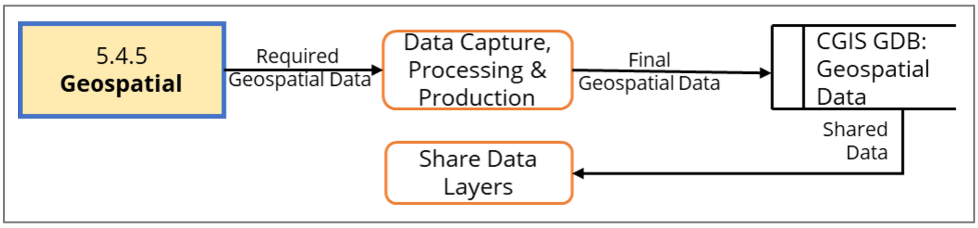

Figure 5-9 Geospatial data flows within the CCT PMS (Part 4 of the parent diagram, Figure 5-5)

Section 5.4 Issues Observed within Current Property Management System and the Management of the Property Management Object

This section presents data collected on issues within the current Property Management System (PMS) and the Property Management Object (PMO) lifecycle during the interviews and supported by documentation and observation data.

5.4.1 CURRENT SYSTEMATIC PROBLEMS REPORTED

The CCT's information management systems has built up valuable data stores, expertise, and systems through the early adoption of GIS (I20,I23,I33) and there is good quality data available to decision-makers and the public (I04,I18). Additionally, efficiency and effectivity have been increased by adopting workflow management tools such as DAMS (I18). However, there are still major issues around data management (I15,I18).

i COMMUNICATION AND SHARING OF DATA IS NOT AS SUCCESSFUL AS IT COULD BE

Many CCT departments require spatial data to function (I01). Unfortunately, inter-departmental data sharing does not perform as it should (I08). Each department that produces spatial data decides which layers to share within the GIS (I04,I14). Thus, there are many datasets that are not shared; they are only used internally within each department (I04,I20). Other departments will not be aware of or have access to these internal datasets. The data that is shared is typically aggregated versions of the original data and, therefore, much of the valuable detail is lost (I20,I23). These original, detailed datasets are only accessible via a formal request to the custodian and as a download at a particular snapshot in time (I20,I23,I33). The shared datasets require intensive cleaning and data management to reach an acceptable state, discouraging sharing (I20,I23).

The decision to share a dataset is based on whether a department believes the data is useful to the rest of the organization or not. Furthermore, departments appear to be protective over their datasets (I04,I05,I14). This may

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[38] Including both digital surface models and digital elevation models.

be due to data privacy, security concerns or an element of possessiveness. For example, the Computer Assisted Mass Appraisal datasets hold an enormous amount of valuable data that is referenced to the LIS key but it is not shared (I20,I23). It is extremely difficult to get permission to access that data, even as a colleague (I23,I50).

ii PROBLEMS IDENTIFIED IN THE TECHNICAL SYSTEMS

When opening the internal or external City Map Viewer, a disclaimer[39] is presented that waives all responsibility of the record-keeping within the GIS (I11,I50). This is seen as problematic because the GIS often holds the only record of certain datasets that are used for decision-making, for example, the zones dataset that carries legal weight (I11). (The zones dataset is used by PBDM in daily decision-making and enforcing land use and development rules.) Therefore, the GIS data should be a consistent, reliable and up-to-date, but the disclaimer waives all CCT responsibility to uphold these values (I11).

Regarding DAMS, the PBDM officials find analysing complex building proposals to be very challenging in the 2D electronic format (I11,I32). Therefore, more often than not, the officials print out the plans to get a grip on the proposal (I01,I09,I10,I11,I32). This negates the paper-less aspect of the DAMS system and reduces the effectiveness of the system (Ibid.).

The CCT has had to implement many custom tools to increase the efficiency and effectiveness of the technical systems. Additionally, every geodatabase has a defined and un-editable schema that sets the data inputs required to control the data uniformity and quality (I33). Therefore, it is difficult to update software or change the format of a dataset because every customization would have to be rebuilt (I14,I30,I40). For example, there is a custom-built Business Systems tool that automatically extracts the length and direction off scanned Surveyor General's Office diagrams (I14).

5.4.2 IDENTIFIED PROBLEMS WITH THE DEFINITION, USE AND MANAGEMENT OF THE PMO

i. ISSUES WITHIN THE LEGAL PROPERTY OBJECT ADOPTION AND MANAGEMENT

Currently, the CCT captures and maintains their own land parcel dataset because the Surveyor General's Office GIS is unreliable (I05,I14,I33). This is acknowledged as a waste of resources and a duplication of records. However, this is seen as the optimum solution until the Surveyor General's Office has a reliable, complete, transparent and up-to-date system in place (I14,I33). Furthermore, there is no formal relationship between the CCT and the Surveyor General's Office and Deeds Office (I14,I31,I33,I36), even though the Spatial Data Infrastructure Act (*SDI*, 2003) requires sharing of data and feedback between entities that use the same datasets (I14).

As stated in 5.3.2i, heights restrictions of real rights, for example, servitudes, are not recorded in the CCT GIS (I30). Until recently, Business Systems was not aware that servitudes could be bound in the vertical dimension and are now investigating introducing this information into the attribute table of that feature class (I30,I33). It is, however, very difficult to introduce a change like this because it entails a change to the established schema of that geodatabase, as stated in 5.4.1i (I33).

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[39] See disclaimer in *Appendix C*.

ii. A LACK OF SPATIAL MEANING IN DATASETS

It is common for spatially relevant data to be recorded as non-spatial data thus removing its spatial meaning (I22,I23). For example, although all valuations data is focused on property, and property is inherently spatial, the data stored is not recorded with any spatial meaning and therefore becomes less useful outside of the narrow purposes of that division (I23). Assigning spatial definition to datasets, adds data value and increases the potential uses of that information (I23).

iii. DATA COLLECTION AND COMPILATION ISSUES OBSERVED

The CCT captures a huge amount of highly useful spatial and non-spatial data. However, this data is typically collected and compiled with only the primary purpose in mind (I15,I20,I23). Additionally, there is little understanding behind the collection and use of the datasets and this often leads to incorrect, disorganised or incomplete data (I11,I15,I23). Furthermore, metadata is captured haphazardly, if at all (I01). It should be noted that Corporate GIS requires specific metadata to be captured for all 365 shared datasets (I50)(*SDMF*, 2017).

iv. OBSERVED PROBLEMS WITH RESPECT TO THE DEVELOPMENT MANAGEMENT SCHEME

In general, the Development Management Scheme (DMS) is overly complex and should be simplified dramatically to make it more accessible to both professionals and the public (I01,I09,I10,I11). For example, the multiple definitions allowed for 'existing ground level' causes no end of problems for the public and decision-makers (I11,I32). A blanket definition for 'existing ground level' is to be introduced by the end of 2020 (see 6.1.5); this is expected to clarify this issue considerably (I10,I32).

Additionally, the PBDM processes are hampered by unnecessary protocols and complex, time-consuming processes (I01,I09,I10,I20). This is illustrated by the increase in unauthorized developments over recent years, indicating that the public would rather pay the administration penalty than attempt the lengthy and expensive approvals process (I01). Furthermore, objections slow the whole process down considerably (I20).

v. IDENTIFIED BUILDING DEVELOPMENT MANAGEMENT PROCESS ISSUES

The National Building Regulations Act (1977) deals predominantly with technical compliance of a proposed building. However, section 7 of that Act is challenging to implement because it is highly subjective (I32)(Ogle, 2017). It deals with the effect of a proposed development on the neighbourhood property values and how it will fit into the environment. The judgement of this cannot be objective as it depends on the assessor's experience and appreciation; this is highly problematic (I32). The CCT has been taken to court numerous times[40] due to the application of this section (Ogle, 2017).

Additionally, there is insufficient continuity between the Land Use Management (LUM) and Building Development Management (BDM) processes (I32). BDM have to compare the land use approvals to the development application but the approvals are not carried through from LUM to BDM and this information is typically lost (I32).

Furthermore, the LOD of property information recorded by the CCT is an issue for BDM (I32). Specifically, BDM cannot uniquely identify apartments in an apartment block because the CCT unique identifier is assigned to the

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[40] Five separate court cases involving the CCT are presented in Ogle (2017).

erf and not the property object (being the apartment, in this case) (I32). BDM requires a higher LOD for achieving their goals of land development (I32).

vi. POTENTIAL PROBLEMS IN CALCULATING PROPERTY VALUE

It is recognised as potentially problematic that the taxable floor space is an area and not the usable volume (I08,I22). The value of a voluminous industrial building or a complex sectional title scheme can be miscalculated by not considering the usable volume (I01,I22).

vii. A LACK OF RECORDS WITH REGARDS TO UNDERGROUND SERVICES

The CCT is an old city with complex underground infrastructure networks (I16). Unfortunately, the exact positions of these networks has been lost over the years through mismanagement and the current records are acknowledged as unreliable and inaccurate (I04,I11,I16). This includes the formerly useful kerbline dataset (I04,I05) that all underground services are referenced to. The roadway can likewise be defined with reference to the kerblines. Therefore, this dataset is sorely missed (I05).

However, when a private company needs to repair, replace or lay down underground service networks, the CCT requires a wayleave application (I16). Through this the CCT should know where networks are being edited or installed, and the knowledge-base could be built up again over time (I16). Unfortunately, this information is not being captured by the CCT and officials do not require the final positions of the as-built networks from private firms (I16).

viii BUREAUCRACY REIGNS AND POLICY IMPLEMENTATION FAILS

It is acknowledged that systems improvement is hampered by bureaucracy in CCT (I01). There are common challenges faced throughout the CCT including budget limitations, a lack of staff resources, crippling bureaucracy and a lack of political will (I04,I05,I11,I30). The CCT, like all large organisations, has difficulty implementing policies that are put in place to achieve identified development goals (I19).

Section 5.5 Conclusion

This chapter presented the CCT Property Management System (PMS), in its current state, including a brief look at the policies and strategies in place that effect property management. The current technical setup is outlined, focused on the capture, sharing and management of property information. Furthermore, each department that contributes to the conceptual Property Management Object (PMO) is introduced, along with their relationships to each other and their responsibilities with regards to the PMO. The data collected and processed using a variety of sources (in-depth interviews, personal work experience and documentation including organisation structures, workflows and policies) shows coherency and therefore, reliability. The following chapter will present the current uses of 3D data within the CCT, and the potential benefits a 3D city model may offer.

Chapter 6 THE CURRENT USE & RECOGNISED NEED FOR 3D IN THE CCT PMS

The CCT has acquired an exceptional amount of diverse and high quality property-related data (I15,I20,I23,I33). This data provides the potential to produce new and innovative products (I04,I15,I33). The current use of, and recognised need for, 3D is the focus of this chapter, including the potential benefits and pitfalls that introducing 3D may have. The data presented here is drawn from the interviews, supplementary documentation, observation data and pulled together using standard case study methodology (see 4.3.1).

Section 6.1 The Current Use of 3D Data within the CCT

The CCT is starting to recognise the high value of the data they own and the power of 3D models (I05,I08,I20)("3DSM", 2019). There are datasets that are being captured in 3D even though a 3D environment[41] does not exist as yet (see 6.1.1)(I04). Furthermore, there are a number of departments that make use of 3D data for project-specific visualisations or analysis. These are introduced in the following sections.

6.1.1 CURRENTLY CAPTURED 3D PROPERTY DATA

Figure 6-1 illustrates a summary of the property information datasets that contribute to the conceptual Property Management Object (PMO), as captured in the Property Value Chain. These datasets are presented in Section 5.3 and are currently captured in 2D, if spatial information is captured at all. The CCT has, however, started to capture 3D datasets that contribute to the PMO record, namely 3D building models and 3D development envelopes. These are introduced below.

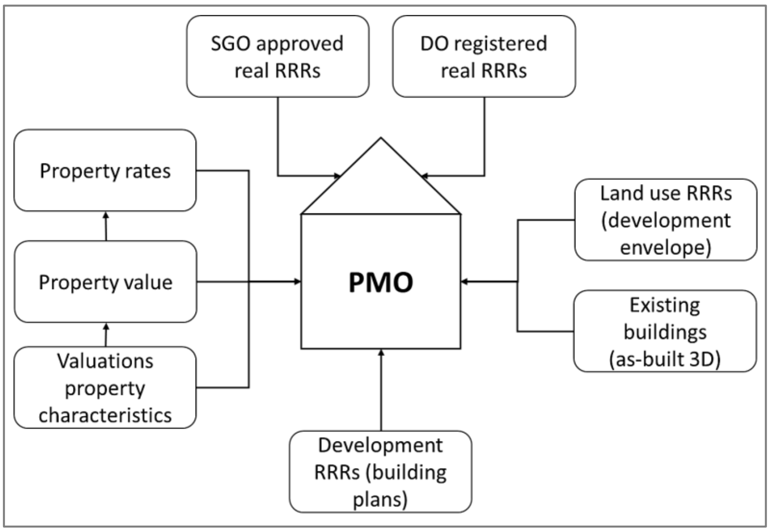

Figure 6-1: The CCT property information datasets that contribute to the conceptual PMO

i 3D BUILDING MODELS

The Geospatial division captures 3D building models stereoscopically from photogrammetric data to an accuracy of 0.3m at LOD 2.2[42] (I04,I06). This dataset has been in continuous production since 2013 (I04). In 2019, 180 000 building models had been captured out of approximately 850 000 existing buildings (I04). With the current resources, it will take another ten years to model all CCT buildings, without taking into account building

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[41] See *Appendix A: Operating Definitions*

[42] As defined by Biljecki *et al.* (2016a), LOD2.2 captures the building roof details and drops this to the ground surface to create the 3D building model. In other words, the walls of the building are in line with the edge of roof and may not represent the true position of the outer walls.

changes. Therefore, the division has focussed on modelling buildings within high interest areas in terms of development such as Urban Development Zones. This increases the usability and relevance of the dataset even though it is incomplete (I04,I06).

The 3D building models are linked to the erf in the CCT GIS via the LIS key (see Section 5.2)(I06). The building identifier adopts the LIS key and adds digits to allow for multiple buildings on a single erf. The identifying key is therefore *erf#_building#*. For example, building 1 on erf 12345 is captured as model *12345_1*. However, a single building may straddle more than one erf. Therefore, it is thought the CCT requires a method of identifying multiple erven to multiple buildings[43] (I05,I06). The unique building identifier has been further modified to allow for recording separate parts within a building, creating the format *erf#_building#_floor#_unit#* (I04). This method has only been adopted by the Geospatial division, even though it is regarded as necessary by other departments (I23,I32).

Unfortunately, the 3D models that developers or architects hold are not required by the CCT for approved new developments and so that valuable data is lost. A 3D record could be required by Planning & Building Development Management (PBDM) when assessing development applications, especially of a defined height or complexity, allowing the CCT to acquire new building models and keep the dataset up-to-date (I01,I04,I05,I06,I09,I10,I11,I32).

ii 3D DEVELOPMENT ENVELOPES ACCORDING TO THE DEVELOPMENT MANAGEMENT SCHEME

The Geospatial division currently models 3D development envelopes (see 5.3.3ii) in specific areas (I04,I06,I33). The focus areas are typically requested by PBDM based on complex applications or high interest areas. Development envelopes are property-specific (see 5.3.3ii) and the envelopes are modelled off the 2D land parcel dataset that contains the cadastral and zone information. The zone rules are applied to each erf to create the building line set backs (2D horizontal limits) and height restrictions (3D vertical limits), thereby defining the 3D development envelope for each erf (I01,I06,I09), as shown in Figure 6-2.

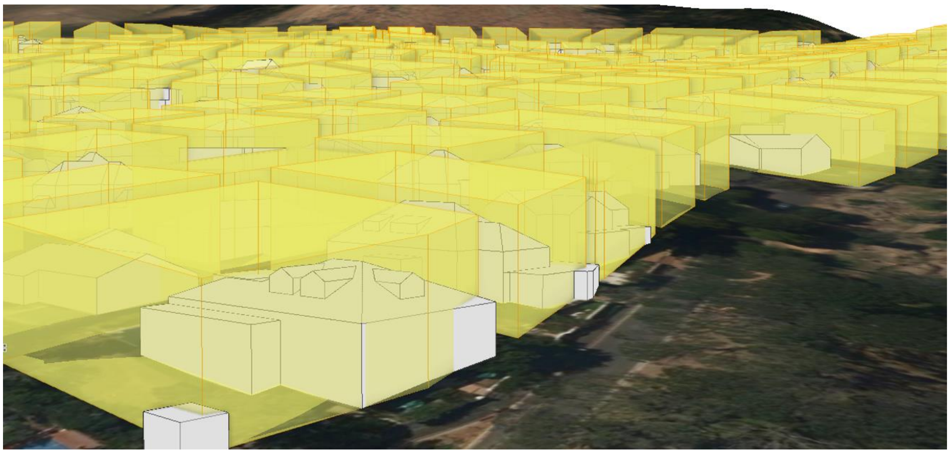

Figure 6-2: An example of the 3D development envelopes (in yellow) manually modelled by the Geospatial Unit to illustrate the land use and development rights in an area of Cape Town. The 3D building models are visible here too.

There are a number of problems in the current process of 3D development envelope modelling. Firstly, the resultant model is static as it captures the zones of a fixed area of interest at a specific moment in time and it

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[43] N erven : N buildings, instead of 1 erf : N buildings or N erven : 1 building

cannot be dynamically updated (I06). Secondly, the CCT zoning dataset can be out-of-date and the shared *Reporting geodatabase* land parcel dataset is not topologically correct (see 5.3.2, Figure 6-3). Topology errors in 2D are exaggerated in a 3D model (I06). The current solution is to request special access to the *Working geodatabase* (see 5.3.2iii) and download the erven in the area of interest (I30,I33). Additionally, an erf can be split-zoned, meaning more than one zone can be applied to the whole or part of that parcel (I06). Whether it is the whole or part is not shown in the land parcel dataset. Furthermore, the multiple ways to define a parcel's existing ground level is problematic for the 3D modelling because it can result in various height restrictions depending on how the definition is applied (I08). Typically, a planner has to be involved in the modelling process to ensure the Development Management Scheme (DMS) rules and definitions are applied appropriately (I04).

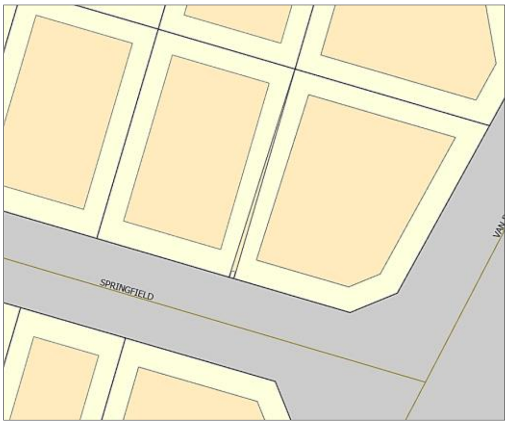

Figure 6-3: An example of a topological error in the land parcel dataset – a sliver is clearly visible between two land parcels.

The DMS rules are enforced to create an envisioned urban landscape for CCT. However, planners do not have the means to visualise the real-world potential impact. Development envelope models can be used for analysis of the impact of the DMS rules, as shown in Figure 6-2. Land Use Management (LUM) have found that by visualizing the maximum development potential for an area in 3D, one can see the real impact of an area's zones and analyse whether the rules are going to bring about the desired urban form (I10,I23).

This type of analysis is demonstrated in Figure 6-4 and Figure 6-5, which reveal the obstructions that are introduced by DMS. This analysis was conducted on a designated scenic drive that has magnificent ocean views. This road is classified as a scenic drive and has specific rules pertaining to it to prevent any neighbouring properties from building higher than 10m with the aim of preserving the ocean views from that road. Unfortunately, as shown in the Figures, 3D visualisations clearly showed that the zoning rules did not preserve the views, because the properties just below the roadside erven may build to far higher levels, depending on their zones. Thus, the models prove that the current DMS will not have the desired impact in that area (I04,I10).

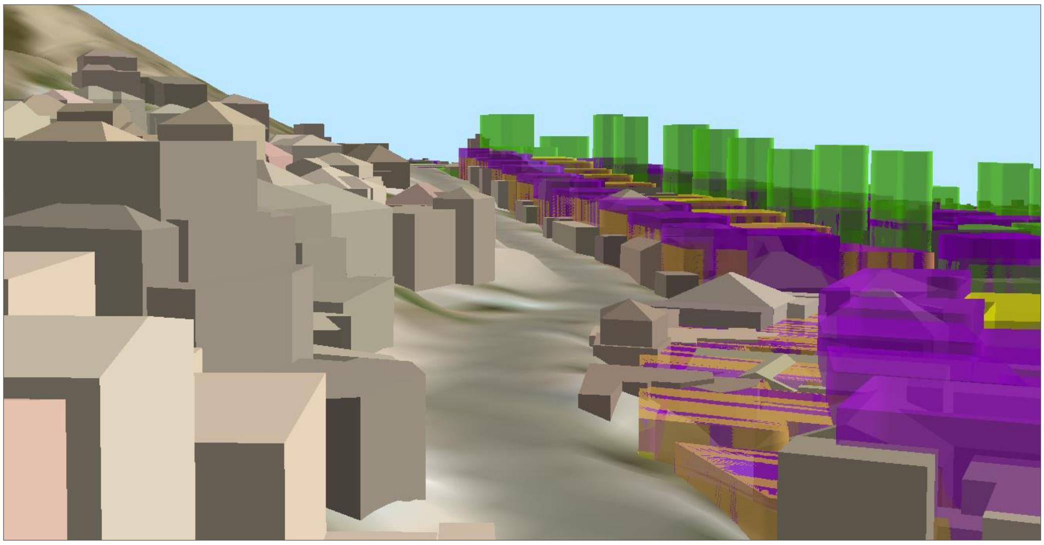

Figure 6-4: A 3D visualization, including the as-built environment, of a scenic drive in CCT that is protected for its panoramic views of the sea and the current DMS rules applied to their maximum potential, obstructing that view.

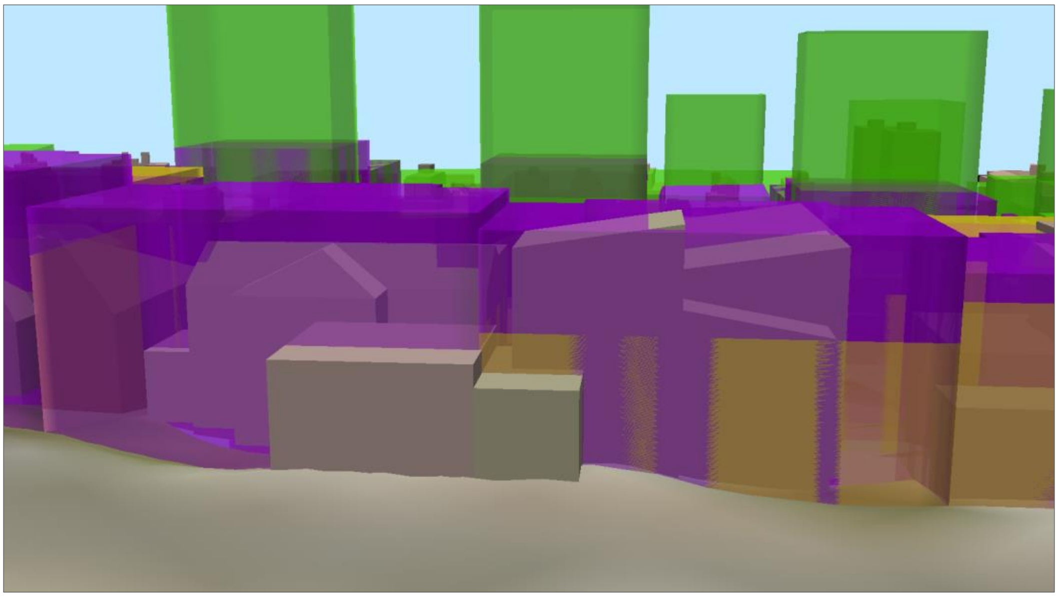

Figure 6-5: The view from the road if the current DMS rules are applied to their maximum potential. The sea views are now obstructed by the tall green development envelopes.

There is an ongoing project to develop a 3D development envelope tool that allows interactive analysis for decision-making (I04,I05,I06). The tool is envisioned to automatically generate 3D development envelopes on-the-fly. This is necessary because the DMS is prone to change and erf zones change often. Therefore, the model should be adaptable and updateable. However, the complexity of the DMS and the issues listed above are holding back the automation of this process (I04,I05,I06,I50).

6.1.2 THE CURRENT USE OF 3D VISUALISATIONS

The Geospatial division compiles 3D visualisations of specific cases on request, by combining the proposed model, 3D development envelopes, 3D building models and the DEM to create visualisations of the real-world situation that look much the same as Figure 6-4 and Figure 6-5 (I06,I09). CCT departments making sporadic use of 3D visualisations include Heritage, Urban Catalytic Investment and Urban Design (I05,I10,I11). Building Development Management (BDM) has not made use of this as yet, but do recognise the potential impact it could have (I32). Land Use Management (LUM) is actively using these visualisations to aid decision-making in complex, high-profile applications, particularly those that fall under the Tall Building Policy[44] (I04,I09,I10,I32).

Complex LUM applications are acknowledged as being difficult to translate into a readable 2D format that adequately represents the proposed development and the potential environmental impact (I09,I17). Furthermore, it is felt that the current 2D format of presenting cases to the Municipal Planning Tribunal is insufficient to support the difficult, and often contentious, decisions that the Tribunal must make (I08). Therefore, the currently-produced 3D visualisations aid decision-making in complex LUM applications (I06,I09,I16) and, in particular, are seen as helpful to the Municipal Planning Tribunal's decision-making process (I08,I09,I11).

Furthermore, 3D visualisations have been found useful in informing the public and resolving conflict situations[45] (I04,I06,I09,I10). For example, in SA law, the right to a view does not exist. This is a highly contentious subject in CCT where views are valuable (I20). A conflict situation in Fresnaye, an upmarket area in CCT, was de-escalated by creating a 3D visualisation of a proposed development and allowing all affected parties to engage with that model (I10). The 3D model was found to be more accessible to the public and professionals involved than the 2D representation (I11,I20).

To aid the modelling process, PBDM are able to request a 3D building model from applicants in complex cases if clarity is needed. Applicants are typically happy to assist if it helps to speed up the approval process (I09,I10,I11,I14,I32). By combining the development envelopes and the current built environment, the proposed building model can be placed into the existing environment. This allows for improved analysis of how the proposal fits into the environment, what departures are necessary, and what the proposed land uses are within the proposed building (I06,I09,I10,I19).

The visualisation product is typically snapshots and fly-through videos that illustrate the application as there is currently no simple solution to sharing 3D visualisations in the CCT (I06,I32). A few of the visualisations have been published to ArcGIS Portal for sharing within the CCT, for example, a Tall Buildings Viewer. This visualisation presents all buildings taller than 60m in the central business district, however, it was a once-off project and is not kept up-to-date (I06,I09).

6.1.3 CITY GROWTH MANAGEMENT LAND USE MODEL

The City Growth Management unit are responsible for achieving the vision of the overarching, metro-scale Spatial Development Framework (see 5.1.4.) and exposing where and why it is not being achieved. The unit has found that 3D models are useful to analyse CCT land use and development trends. To understand these trends for over 850 000 erven is challenging, if not impossible in 2D (I19,I23,I24). To incentivise more development, this unit creates land use models to visualize different scenarios and understand the intensity and diversity of land use development in specific areas. For example, by combining the 3D development envelopes with the existing 3D as-built environment, one can produce a picture of the excess development rights in the CCT. This illustrates how much potential is available and where it is not being taken up (I19,I20,I23,I24).

Additionally, a transport-orientated development scenario was developed to visualise the required high density, mixed-use developments around areas with good transport connections. This scenario illustrated to planners

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[44] See 5.4.3.5.3.3ii.

[45] See Bo Kaap Monster case in *Appendix D*.

how much development and what combination of land use is possible, in 3D, with regards to the existing transport facilities. This method aids transport and infrastructure planning too (I19,I23,I24). Furthermore, value-added products are created by integrating and comparing different CCT datasets in 3D, for example Property Value Chain property data and census data, to analyse spatial relationships in a broader context. This allows for an improved understanding of where people live, work and travel, and the patterns of urban growth. These products are not typically shared (I19,I23,I24).

6.1.4 SOLAR ENERGY AND FLOODPLAIN ANALYSES

The Geospatial division conduct 3D spatial analyses on special request (I05,I06). These have included solar energy or shadow analyses, and flood plain or sea level rise analyses (I05,I06). This type of analysis generally makes use of the 3D as-built environment and the digital elevation models. Refer to Figure 6-6; the CCT Property Management department aimed to install solar panels on one of their office blocks. However, the development rights in this area allow for taller developments. Therefore, the Geospatial division analysed how much daylight the building roof could expect if the maximum development rights were taken up by the neighbouring erven. This allowed the department to make an informed decision on whether or not to install the panels (I05,I06).

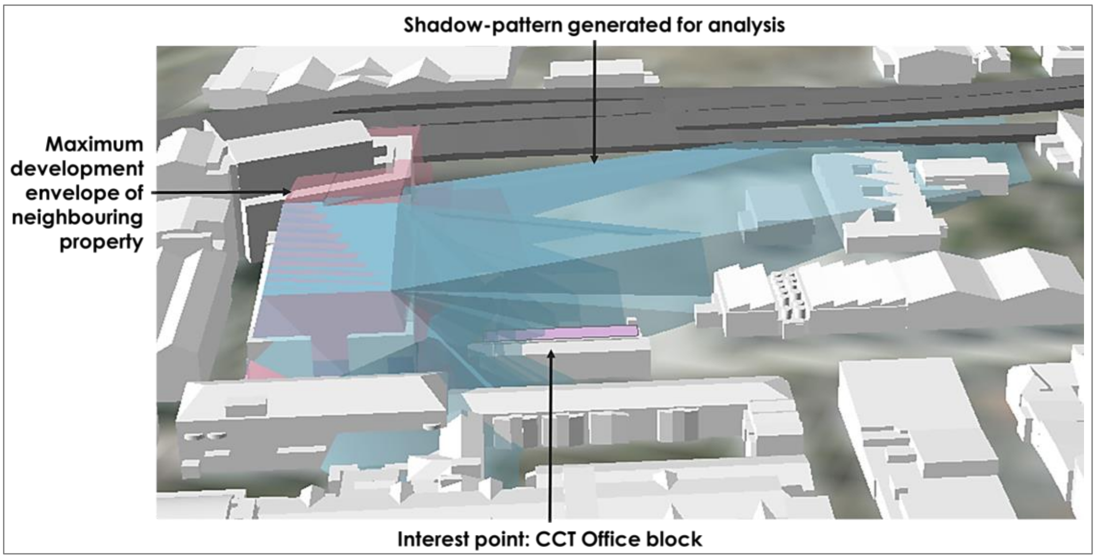

Figure 6-6: A shadow analysis showing the quantity of daylight a building roof could expect if the maximum development rights were taken up by the neighbouring erven.

6.1.5 THE GROUND LEVEL MAP, A PLANNING TOOL

The CCT is moving forward with legislating both a digital elevation model and a contour plan to legally define the existing ground level for the whole metro at a given instant in time, specifically for land use and development pruposes (I04,I05,I23). This surface and contour plan are derived from 2019 LiDAR data and will be known as the CCT Ground Level Map (see Figure 6-7)(I04,I05,I50). The "City of Cape Town Ground Level Map means a map approved in terms of the development management scheme, indicating the existing ground level based on floating point raster and a contour dataset from LiDAR information available to the City" ("MPBL", 2019: 8). It is envisioned[46] that the provision of an unbiased definition of ground levels will simplify the definition of building

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[46] In one area of CCT, Llandudno, there is a contour map from the 1980's that is used to define existing ground level and it has reduced conflict over the years (I08,I32), although this is debated by some (I11).

heights and the Planning & Building Development Management (PBDM) approvals processes (I04,I05,I23,I26,I27,I34).

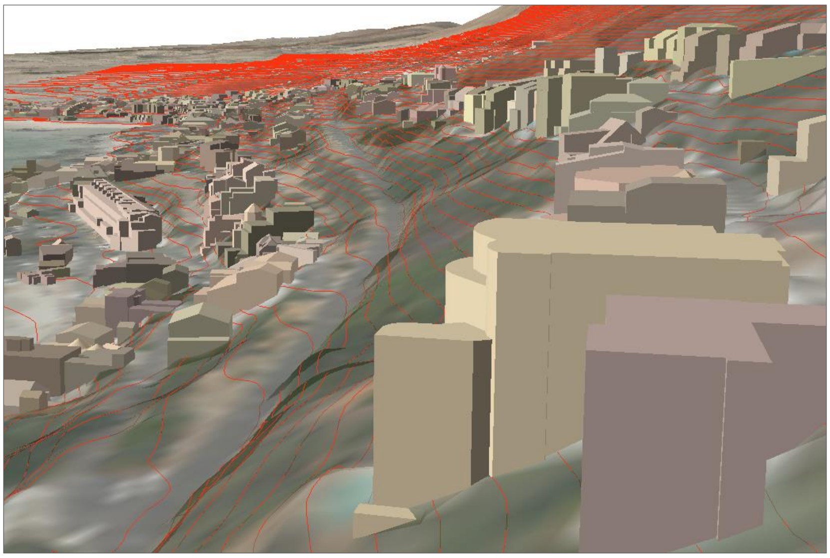

Figure 6-7: The Ground Level Map, a digital elevation model and a contour plan, shown in a 3D environment.

The Ground Level Map can be offset to create a parallel surface that defines the maximum building height limit for a zone (see Figure 6-8)(I04,I05). In a 3D environment, this will ease the process of checking whether a proposed building falls within the height limitations. Therefore, this surface will simplify the approvals process (I04,I05). This is seen as a relatively small introduction into the CCT Property Management System (PMS) that paves the path towards 3D environment.

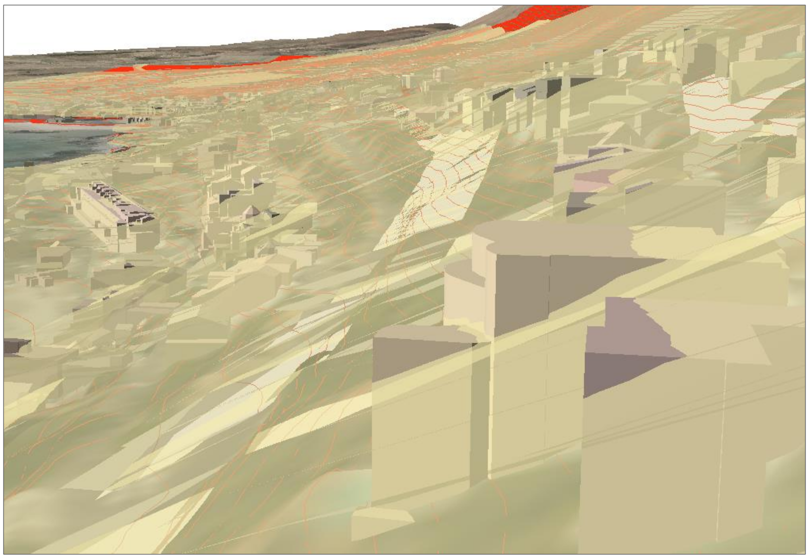

Figure 6-8: The Ground Levels Map offset to the maximum development height of the area, creating a parallel surface to illustrate buildings that would require height departures

Section 6.2 The Possibilities that 3D Could Offer

The possible benefits of introducing 3D into the CCT Property Management System (PMS) are numerous and many are showing an interest in 3D; 73% of the interviewees see the introduction of 3D as positive and necessary. A group of CCT employees have begun working on a proposal to introduce a 3D Smart City to the CCT ("3DSM", 2019)(I04,I06,I16,I23). This proposal includes the foreseen potential benefits and is used as a supplementary data source to the interview data.

A summary of the possible benefits is presented in the graph below, Figure 6-9, as drawn from in-depth interviews using the analytical framework described in Section 4.3.[47] These are ranked according to the number of interviewees that named that benefit of 3D. The interviewees were asked their opinions on the purpose and benefits of a 3D record.[48] Although visualisations were typically mentioned first by the respondents, for the most part interviewees drew out many other, diverse benefits as they spoke. The most common thought that came out of these conversations is that a 3D property record supports efficient and effective decision-making. The specific points regarding each benefit are presented in the subsections below.

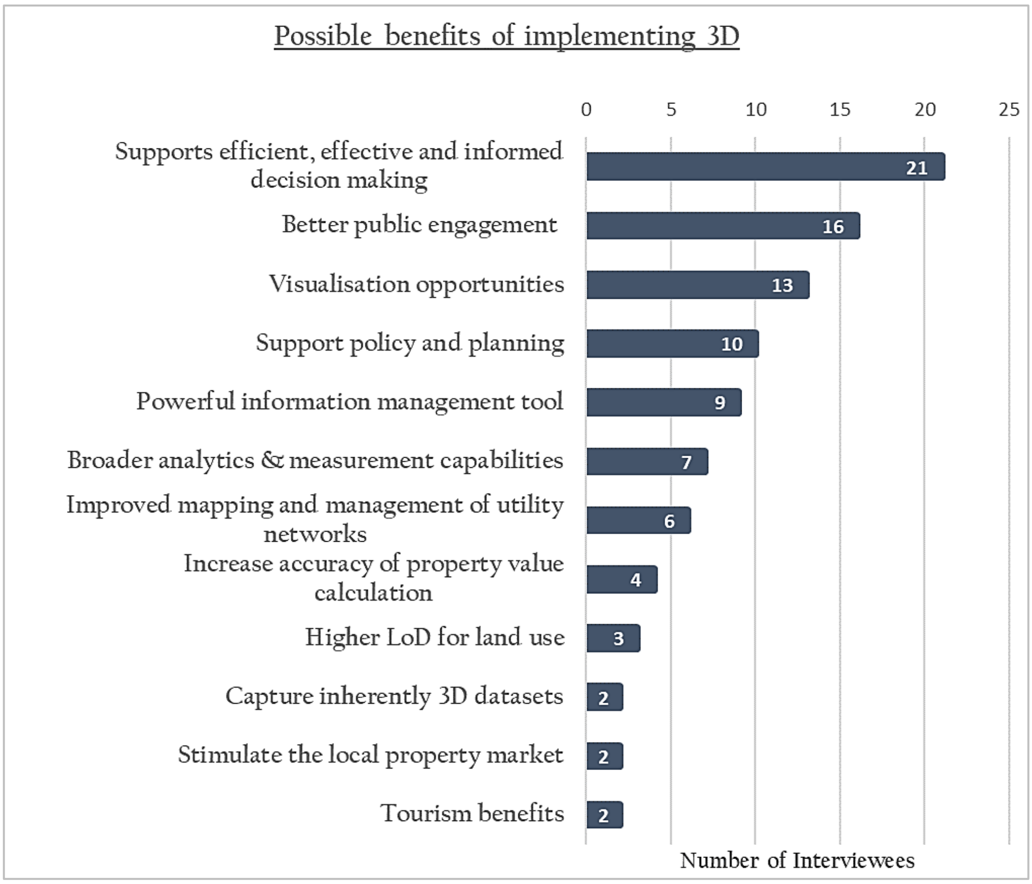

Figure 6-9: A summary of the possible benefits of 3D as drawn from the interview data

6.2.1 SUPPORTS EFFICIENT, EFFECTIVE AND INFORMED DECISION-MAKING

A 3D environment could support informed and data-driven decision-making through reliable evidence, improving the functionality and efficiency of the current decision-making practises (I05,I10,I14,I15,I17,I18,I23). 3D models may provide context, clarity and an increased understanding that can aid CCT PMS processes (I01,I04,I05,I09,I11,I17,I26,I27,I32). The interpretation of 2D maps or building plans is challenging (I05,I07,I08) and more especially in the digital form (I06,I09,I11,I32). Additionally, the Development Management Scheme (DMS) defines the development envelope in 2D setbacks and height, defining a 3D volume. Therefore, all PBDM applications should be dealt with in 3D (I08). The heights of developments are increasingly important to consider

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[47] The 3D Smart Model proposal was not used in the creation of this graph.
[48] Refer to *Appendix B* for the Interview Guide.

under the current intensification policy[49] and 3D models can support efficient analysis of the impact of a proposal's height and bulk (I08,I11).

Dynamic 3D models that allow for interaction and visual impact analyses give clarity to complex Property Value Chain cases (I01,I04,I05,I06,I09,I10,I11,I17,I20). 3D is necessary to adequately see and analyse a proposal's impact on the surroundings (I03,I07,I08,I09,I10,I11,I15). Ideally, a proposed development could be compared to the existing environment and the potential development envelopes to quickly analyse whether approval can be given (I03,I04,I08,I09,I11,I32). For example, 3D would be incredibly useful to the Municipal Planning Tribunal (see 5.3.3i) that has to make difficult decisions in a limited time frame (I08,I11). This would speed up the approvals processes, provide credible evidence for decisions made (I05,I08,I10,I14,I23) and increase confidence in those decisions (I06,I08,I32). Furthermore, Building Development Management (BDM) foresee that an analysis of planned developments in a 3D as-built environment, including the utility networks and kerbs, could be very useful to making efficient and effective decisions (I32).

In Land Use Management (LUM), if 3D building plans could be automatically checked against the development envelope, it would save time and negate human error (I01,I10). Furthermore, if a 3D model is mathematically and objectively produced, the CCT can reduce subjectivity from the PBDM processes (I05,I10,I28)("3DSM", 2019). Currently, the CCT or the public can produce a visualisation that is biased[50] in a certain direction to sway decision-makers. A 3D visualisation may decrease the risk of bias (I15). In BDM, the automated comparison of the as-built building model to the approved 3D plans could trigger a notification to the building inspector, saving time and further removing risk of corruption and human error in Property Value Chain processes (I16,I32).

6.2.2 BETTER PUBLIC ENGAGEMENT

A 3D model may promote better engagement with stakeholders and the public (I09,I14,I16), support public participation and engage more sectors of the community in the decision-making process ("3DSM", 2019). 3D information provides a relatable perspective (I05) that is easier to understand than 2D maps or plans and it is simpler to communicate spatial information in 3D (I06,I09,I10,I14,I32). An informed public is empowered and less likely to be uncertain of the changes necessary to achieve the required development intensification (I04,I08,I16,I20).

By improving public engagement and information on developments and changes planned across the CCT, the number of objections to proposals may be reduced, thus increasing the efficiency of the Planning & Building Development Management (PBDM) process (I04,I05,I06,I20). Many objections received can be attributed to misunderstanding the proposal, because 2D plans are challenging to interpret, even for a trained professional (I04,I05,I08,I10,I11,I20,I32). Any objectors can be engaged with a 3D model to aid mediation and dispel any doubts (I10).

Similarly, a 3D visualisation can help avoid the spread of misinformation and aid in conflict resolution (I06,I14). A 3D platform provides an excellent communication tool that can be used to resolve potential or active conflict and possibly reduce the number of PBDM court cases (I06,I10,I16)("3DSM", 2019). 3D visualisations have been

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[49] See 5.1.4 for more on this policy

[50] See *Appendix D: Bo Kaap Monster case*.

used by the CCT in litigation and were found to be extremely useful to clarifying a case[72] to all parties involved (I28).

Moreover, a publically available 3D development envelopes dataset would create an informed public and informed buyers (I04,I05,I08,I09,I16), stimulating the property market (I20). The knowledge of how the CCT foresees the development of the city may cause an outcry initially as the public come to terms with their and their neighbours' development rights (I04,I06,I10). However, in future, it would aid avoiding potential conflict and reduce objections in the future, as only valid objections will be raised (I04,I05,I06,I20).

6.2.3 VISUALISATION OPPORTUNITIES

The improved visualisation capabilities made possible in a 3D environment is regarded as the primary benefit of 3D (I01,I04,I05,I08,I19). 3D information can clarify situations by providing a visual perspective that is relatable and understandable, supporting CCT LA work (I05,I06,I07,I16). Visual impact analysis presents the real world impact of a proposed development (I05,I10,I15,I32). The context of development is becoming increasingly important and decision-makers and policy-definers should start taking 3D into account (I08,I11,I15). CCT cannot view proposals in isolation any longer (I10,I15). 3D visualisations allow CCT officials, private professionals and the public to easily analyse the impact of potential developments ("3DSM", 2019).

The context of a case is especially important to BDM when analysing a proposal in terms of National Building Regulations, Section 7 (see 5.3.3iii.)(*NBR*, 1977)(I32). Furthermore, a 3D visualisation could be useful to Valuations for analysing a property's relationship to its environment (I17). Additionally, the visualisation of the development envelope is particularly useful (I01,I04,I05,I08,I19,I20). Complex DMS rules or title deed restrictions can be difficult to grasp and 3D could be useful to model this data for better understanding (I26,I27). In other words, a 3D visualisation may be useful to clarify the RRRs associated with a property (I04,I06,I09,I26,I27).

6.2.4 SUPPORT POLICY AND PLANNING

It is acknowledged that better tools are required to fully understand land use and development, and their effect on attaining the CCT policy goals (I08). A 3D analysis strategy supports policy development by allowing for evidence-based planning through more realistic visualisation of how the city is developing (I10). 3D information is essential to understanding and managing urban growth and the intensification process necessary to guide policy implementation (I08,I14). It allows for the analysis of the existing built environment versus proposed development versus the desired future outcomes as defined by CCT policy ("3DSM", 2019). A 3D analysis of development patterns can aid CCT officials in making the correct decisions to achieve policy goals (for example, the Spatial Development Framework) (I23).

The CCT is struggling to attract sufficient property investment to attain its policy goals (I20). The development RRRs and incentives exist to promote densification, but these RRRs are not being taken up by developers (I20). An analysis is required of the residual development RRRs and where these are, in 3D, and why these are not being optimised, to promote and encourage densification to achieve policy (I10,I18,I19,I20,I23). This analysis should include the existing 3D built environment, including infrastructure, to be meaningful (I19).

Not only can CCT model the current environment, but likewise the 3D development potential of an area, illustrating the impact on the future environment (I04,I05,I06,I10,I18,I20)("3DSM", 2019). The densification development policy is highly contentious and 3D can make the envisioned development more accessible and acceptable through increased public understanding (I04,I24). This could encourage and promote the necessary investment and development to achieve the CCT goals (I10,I17,I20).

Moreover, 3D development potential analysis allows one to visualise and analyse the impact of the Development Management Scheme (DMS). CCT can test the proposed development rules for a certain area and see the potential effect on the environment. This allows CCT to analyse whether the DMS regulations will have the desired impact that they require to achieve their policy goals (I10,I14). Furthermore, 3D facilitates the protection of urban spaces by promoting better evaluation of the impact of the DMS regulations and of proposed developments on the urban landscape (I10).

Additionally, 3D supports the analysis of service delivery versus the bulk of the built environment (I10,I17,I24). An analysis of what the utility network service capacity is defines the volume of developable bulk and affects policy implementation. Furthermore, it would facilitate the improvement of service delivery by more accurate predictions and planning of utilities usage (Ibid.).

6.2.5 POWERFUL INFORMATION MANAGEMENT TOOL

A 3D city model would provide a more rounded approach to information management by promoting collaboration and supporting joint decision-making across specializations and between the CCT and the public (I15)("3DSM", 2019). It would provide an improved clarity, reliability and accuracy in the record-keeping, allowing for better management, data analysis and an increased understanding of property information (I14,I16,I32). However, a higher level of detail in property information records is required to bring about these improvements to information management (I04,I20,I32).

The future, if the Spatial Development Framework (2017) is adhered to, will see far more mixed-use and mixed value[51] developments to achieve the goal of densification (I17). This complexity will be difficult to understand and manage in 2D, and if there are many of them, it becomes near impossible (Ibid.). In 3D, this complexity becomes easier to grasp and handle. Additionally, 3D records would aid the separation of property that falls below road and road reserve (I21,I31). These properties are currently difficult to manage and being able to separate these property objects would greatly improve the CCT processes (Ibid.).

6.2.6 BROADER ANALYTICS AND MEASUREMENT CAPABILITIES

Creating a 3D model as the base layer to which all other property datasets (for example, valuations, utilities consumption, census and income data) can be related, opens up another dimension of analytical possibilities. This added meaning would increase CCT understanding of the urban landscape and adds another dimension in which to analyse spatial patterns (I04,I14,I16,I23). The CCT will then be able to gauge relationships across the metro and look at the broader, real-world contexts of the data (I16).

Additionally, there is the potential for visual or engineering-based analytics, for example, solar energy, wind tunnelling or pollution assessments, shadow or floodplain analysis, or the identification of urban spaces that require protection (I04,I05,I06,I10)("3DSM", 2019). Furthermore, there is the added capability of measuring heights and volumes (I04).

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[51] Mixed value refers to a combination of different valued properties that appeal to different income groups in one building.

A 3D city model could have safety and security benefits, and it should be noted that CCT are looking at the possibility of adding 3D datasets to the existing emergency services viewer. This data is seen as potentially life-saving in an emergency, for example, if used to identify what floor of a building a fire is on and the potential risks in the environment (I38).

6.2.7 IMPROVED MAPPING AND MANAGEMENT OF UTILITY NETWORKS

Utilities are inherently 3D datasets and an improved knowledge of the positions of these networks would benefit the management of these services (I04,I05,I11,I23,I30). 3D supports the ability to assess both the coverage and the potential of that network ("3DSM", 2019). The CCT is showing interest in creating 3D utility network records. For example, the Water and Sanitation department have motivated to capture the water reticulation network in 3D (I04). However, there are currently insufficient resources to create this dataset; it would require detailed invert levels data, pipe diameters and flow directions (I04). Some of this data does exist, but not spatially and not consistently. Furthermore, it is noted that a dataset that provides the 3D position of utilities would be useful to BDM's approval process (I32). This is seen as the largest benefit a 3D record would bring to the BDM (I32).

6.2.8 INCREASE ACCURACY OF PROPERTY VALUE CALCULATION

A more accurate estimation of property market values results in fair and effective property taxation which in turn benefits the public and the CCT (I17). A 3D city model would improve market value calculations ("3DSM", 2019). This value is partly determined by the highest and best use of that property which is dependent on the physical aspects of the property. Furthermore, it is a function of not only 2D floor space, but the usable volumetric space. This is a 3D characteristic of a property and is critical to calculating a property's market value (I20).

The 3D location of a property is very important when it comes to determining market value. Currently, the property data recorded to calculate a property's value is attribute data whether spatial or not. 3D data could illustrate the property's relationship to the neighbourhood and provide a truer representation of the property's environment, views (I18), security level and location (I17,I22). This would result in a more accurate property value being calculated. However, the data is only as valuable as it is up-to-date. Valuations require current data to perform their functions (I17,I20,I22). Furthermore, the level of detail is crucial for 3D data to have added value (I17,I18,I20). There will have to be a level of detail to property object level, rather than to building or floor level, for this information to be useful to valuations' calculations.

6.2.9 ADDITIONAL BENEFITS AS NOTED BY INTERVIEWEES

Firstly, a higher level of detail in a 3D environment will not only benefit Valuations in calculating more accurate property values (I17,I18); it would provide land use data per floor or unit to departments like Planning & Building Development Management (PBDM) and City Growth Management for extended analysis capabilities (I14). This can be done by attributing property ownership to a volume rather than an area ("3DSM", 2019).

Furthermore, datasets that are inherently 3D, for example, flood plains, steep slopes or heighted servitudes, are valuable datasets and are better understood in 3D (I01,I11). These datasets often have a direct effect on the use of property, usually in the form of a use or development restriction (I50). It is necessary to analyse these datasets in 3D to fully understand the impact on the properties in that area (I01,I11).

Moreover, a 3D city model could stimulate the local property market (I18,I20). An efficient property market is underpinned by accessible and adequate information. Introducing 3D would increase the public's understanding of the built environment and the development potential available. This could increase the efficiency of the CCT property market, stimulating the local economy and development (I18,I20).

Finally, it is thought that a 3D city model can provide tourism benefits by creating an immersive artificial reality or online walk-throughs of Cape Town that help promote the city's sights (I07,I16)("3DSM", 2019).

Section 6.3 Concerns regarding moving to 3D

The concerns interviewees had with regards to moving into a 3D Property Management System (PMS) environment are shown in the graph below, Figure 6-10. Each potential pitfall is ranked according to how many interviewees supplied that subject as a concern. The interviewees were asked, "Can you see any potential pitfalls of introducing a 3D record into the CCT system?" [52]

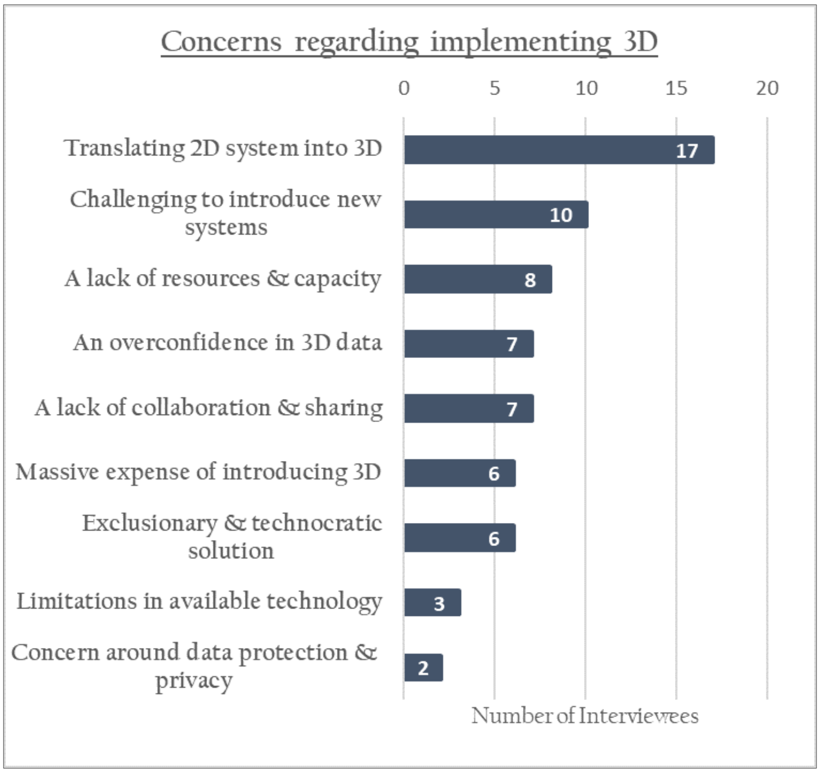

Figure 6-10: A summary of the potential problem areas with regards to introducing 3D into the CCT PMS as drawn from the interview data

6.3.1 TRANSLATING THE CURRENT 2D SYSTEM INTO 3D

The Development Management Scheme (DMS) is overly complex with regards to the third dimension. The current definitions to determine development heights in the DMS are interpretable, complex and do not lend themselves to automation (I01,I04,I05,I09,I10,I11,I22,I26,I27). Furthermore, the DMS height definitions are difficult to understand and apply, leaving both the public and many built environment professionals at a loss (I04,I06,I08). There are too many ways to define the existing ground level, leaving it open to interpretation and contestation (I06,I09,I10,I11). The DMS regulations are often a function of height above that level (I11). Therefore, it should be clearly defined to avoid errors or misunderstanding (I11). When dealing with land use applications, Land Use Management (LUM) frequently have to check every applicant's base height definition and the zone

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[52] Refer to *Appendix B* for the Interview Guide.

rules applied to be sure the applicant understood the regulations correctly. This creates more work and requires more resources in LUM (I11). To move towards a 3D system, the CCT would need to introduce simple, unambiguous solutions to definitions in the DMS to avoid conflict, assist modelling and increase the efficiency of the processes (I01,I04,I05,I06,I08,I10,I11).

A 3D model will require a topologically correct and up-to-date database of property information (I33). Connecting and integrating all the necessary datasets into this will be incredibly challenging (I23) and it will require human and software resources that do not currently exist (I33). Furthermore, to produce a 3D environment, CCT requires a higher level of detail (I17) that is followed consistently throughout the CCT departments (I04,I23). This will be difficult to implement but it is necessary to support integration, break down the existing information silos and improve collaboration (I04,I23). Moreover, the CCT GIS cannot currently relate multiple uniquely identified erven to multiple uniquely identified buildings (N erven : N buildings) as is necessary to fully capture the relationships between property in CCT (I04).

As with 2D PBDM applications, the correct 3D plans or models must be submitted, and this is, currently, often not the case (I06,I09). Too often the 2D plans are out-dated, incorrect or contain too little information to extract any relevant meaning for the decision-making process. This problem will carry over into 3D and may be even harder to identify in that environment (I06,I09).

6.3.2 CHALLENGING TO INTRODUCE NEW SYSTEMS

Currently, all CCT data and workflows are 2D-based (I09). Even so, many staff members have not completely bought into 2D digital data, let alone 3D data (I10). It will be challenging to ensure all staff can work with and understand a 3D-system (I09). This is an institutional issue that can only be changed by sincere managerial buy-in to reinforce system changes (I10). Therefore, the CCT management need to grasp the tools available and the potential benefits (I10). Unfortunately, people want to see the benefits of a new system upfront and that will hardly be possible with 3D (I10,I16,I17). Furthermore, introducing 3D will require considerable political and public buy-in, including private parties like developers who hold important property information resources that CCT need to build the 3D system (I16,I18,I19). Furthermore, unless well-communicated, a new approach could result in public angst or discord (I06,I10).

New systems are exceptionally hard to roll out and manage (I11). It is necessary to have robust debate when introducing new technologies or systems; if a tool is not well planned it can have unintended consequences (I20). Furthermore, the top-level management and politicians who implement new systems, do not use those systems and therefore, lack an understanding of the system issues (I01,I11). Any issues with new systems that are reported are typically ignored, because the system should be seen as a success politically. This has the effect of throttling any new system and hampering improvement (I01,I11). There is a risk that a 3D city model may be one of these systems if introduced too quickly and without enough research and support (I11).

6.3.3 A LACK OF RESOURCES AND CAPACITY

A 3D environment will push CCT resources and capabilities (I19). Currently, the CCT have limited capacity to conduct the necessary research and development, and for the final implementation (I04,I05,I09,I10). Furthermore, technology changes quickly and it will be a challenge to keep up in terms of resources, skills and training (I04,I05,I16,I19). Currently, maintaining the 2D datasets is a challenge for the CCT and data archiving and storage capacity are limited (I04,I32). Therefore, maintaining 3D data may be virtually impossible (I04,I05).

As stated, it will be necessary to move the focus of the CCT GIS to a higher level of detail. Currently, the CCT does not have a full 2D building footprint dataset due to a lack of capacity (I04,I05). When moving from an erf to a building level of detail, let alone a floor or unit level of detail, the number of features more than doubles. This step, along with capturing the kerblines, is an essential foundation block of a 3D city model (I04) and the CCT does not currently have the technical, financial or human resources for establishing or maintaining these datasets (I04,I05,I09). Unfortunately, the geospatial datasets are currently not of a high enough accuracy to be used for engineering purposes (I05). Furthermore, the more 3D the CCT produces and uses, the more evident the benefits will be, the more 3D data will be required and the more difficult to keep up (I05).

6.3.4 AN OVERCONFIDENCE IN THE RELIABILITY OF 3D DATA

An overconfidence in 3D information can be dangerous, because 3D is only a representation of reality. It seems like a realistic representation and people may put too much faith on that in decision-making (I07). It follows that 3D is a powerful tool that can be abused (I07,I08). 3D visualisations can deliberately sway decisions because they appear more trustworthy than a 2D representation (I04,I05,I07). Specific perspectives can be used to mislead and manipulate decision-makers and public opinion (I04,I05,I07). This can be partially solved by introducing an interactive model rather than using fly-through videos or image stills of the 3D environment (I04). The 3D representations should be kept mathematical and objective as far as possible (I05,I11).

6.3.5 A LACK OF COLLABORATION AND SHARING

Within the CCT there is little meaningful collaboration between departments because each department has its own agenda (I04,I07,I08,I15). Collaboration and consistency is required (I18,I26,I27) to combine and align datasets, break down the existing PMS silos and transcend specializations (I07,I15,I20,I23). To facilitate this, both Valuations and IS&T departments have to commit to this ideal (“3DSM”, 2019).

Furthermore, there is no relationship between the CCT and the Surveyor General’s Office and Deed’s Office (I26,I27). A 3D Legal Property Object (LPO) cannot exist without collaboration of some kind between these agents to capture all the relevant RRRs in x, y and h (I05,I20). The CCT DMS determines the height to which a property can be developed and this value would be required by the Surveyor General’s Office if they were to create a 3D LPO record (I05).

6.3.6 EXCESSIVE EXPENSE OF INTRODUCING 3D

A 3D city model will be expensive to build and maintain (I04,I05,I10,I16,I17,I20) and there will be an indeterminable cost deriving from the unknowns (I10). The potential value has to be analysed carefully with regards to the costs (I05,I17). Unfortunately, it will be difficult to show the value of the benefits versus the cost, because they will mostly be indeterminate (“3DSM”, 2019). The CCT, let alone the public, will not provide the required budget unless the benefits are clearly shown (I16).

6.3.7 INCREASED COMPLEXITY - AN EXCLUSIONARY AND TECHNOCRATIC SOLUTION

A 3D approach may be technocratic and therefore, an exclusionary and inaccessible solution to the majority, especially the poor (I02,I08,I11,I18,I20). Even the current 2D format is inaccessible to many of the citizens (I10). Furthermore, the development processes may become onerous and expensive, and this could result in an increased number of illegal developments (I20).

The technical capabilities of the public seem to be limited. For example, PBDM clients send scanned copies of pdf documents because they cannot create an e-signature. This is a basic technological skill that should be easy to learn. It is therefore doubtful whether the public will cope with learning to operate in a 3D environment (I32).

6.3.8 LIMITATIONS IN CURRENTLY AVAILABLE TECHNOLOGY

Serving 3D data will be a challenge. It is not currently possible to share 3D datasets because of software limitations and there is little support for 3D projects (I04,I06). It is possible to create ArcGIS web scenes that can be shared through the online platform, Arc Portal, but each scene has a size limit of 15Mb (I06). This is a very small file in terms of 3D data and puts a harsh limit on the ability to share 3D data. Furthermore, these scenes are not updated-on-the-fly, resulting in a fixed solution for a project-based approach (I06).

Additionally, there is a lack of technical compatibility between CCT departments in terms of the software they use and the methods of data capture and processing (I32). However, some staff in IS&T are of the opinion that there is no difference between serving 2D and 3D data (I32). The problem will rather be converting all CCT data into a standard format that is spatially referenced for integrating ("3DSM", 2019).

6.3.9 CONCERN AROUND DATA PROTECTION AND PRIVACY

A higher level of detail of property information would be required to build a 3D city model (see 6.2.9), but the public may not want the CCT to have access to such detailed information (I16). Additionally, creating a public 3D record of utility networks could put the CCT at risk of theft, abuse or damage to those networks (I05).

Section 6.4 Conclusion

There is an increasing complexity in the urban landscape that will see an increased number of mixed-use (I02) and overhead and underground developments (I32). These increase the challenge of keeping adequate 2D property records (I32) and there is agreement that CCT does not have an adequate solution to handle complex Property Management Object (PMO) cases in the Property Management System (PMS)(I01,I04,I10,I16,I30). There will be teething problems when introducing a new system and it will be resource hungry, but 3D could improve efficiency in the long run (I10). However, the CCT would need to be convinced that this is the right path before resources and capacity are increased (I04,I09). The coherence of the data presented here shows strong internal validity. Outlier responses are acknowledged and dealt with in the weighting scheme used (common responses are weighted more than uncommon responses).

Chapter 7 ANALYSIS AND DISCUSSION OF THE FINDINGS

This chapter presents an analysis of the current state of the CCT Property Management System (PMS) and the management of the Property Management Object (PMO). This discussion is drawn from the narrative of the system-in-focus set out in Chapter 5 using the adopted analytical tools (see Section 4.3). Furthermore, the potential implications of introducing 3D are presented here based on the data presented in Chapter 6. This chapter attempts to answer the research questions (see Section 1.3). The analysis informing the discussion is bolstered by the literature (see Chapter 2) and held up against the foundational land administration theory (see Section 3.1). It should be noted that this is a single case study and that, although other cases may have similar challenges and benefits, these cannot be confirmed or denied in this research.

Section 7.1 The Capabilities and Limitations of the CCT PMS

The CCT Property Management System (PMS) is adopted in 1.1.1 as the system-in-focus within which to analyse the capabilities of SA local government to achieve the goals of successful land use, development and valuation with respect to the PMO. An effective LAS requires up-to-date and comprehensive property information, and standardisation that allows for integration and interoperability (see 2.2.3, Section 3.1). The CCT's information management systems have improved greatly over the past two decades and there is good quality data available to decision-makers and the public. The early adoption of GIS has allowed the CCT to build up valuable data stores, expertise, and systems (see 5.3.2). Additionally, introducing workflow management tools like DAMS has increased efficiency and effectiveness. However, there exist definitive silos within decision-making processes and information systems, as well as issues within the definition and management of the PMO. These are presented below.

7.1.1 A LACK OF COMMUNICATION WITHIN THE LAS

The Surveyor General's Office and Deeds Office hold separate, independent records (see 5.1.2i), although tied by the erf number, creating the first examples of silos within the SA LAS (see 2.2.3). If a servitude is created in a new title deed or by notarial deed only and it is not necessary to define the boundaries on a survey diagram, it will not be reflected in the Surveyor General's Office records. This is problematic for the CCT, as Business Systems only queries the Surveyor General's Office records (see 5.3.2i, Figure 5-6) and, therefore, the real RRRs registered through the title deeds alone are 'invisible'. To compound this, Valuations captures only RRRs registered within the Deeds Office (see 5.4.2ii, Figure 5-6). Furthermore, Valuations and Business Systems do not have a working relationship and do not share Legal Property Object (LPO) data directly (see 5.3.2, Figure 5-6). This is disconcerting because both departments are working towards the goal of a complete LPO record in the CCT PMS. The LPO data captured from the title deed into the Government Revenue Management system (GRM) should complement or merge with the land parcel dataset that is captured by Business Systems from the Surveyor General's Office diagrams; creating a complete, spatially-referenced GIS dataset. This would align with the good governance principles (GGPs) requirement of comprehensive and up-to-date property records (see 3.1.4). Unfortunately, the CCT does not have a record of the full-picture of real property RRRs from either perspective.

Additionally, neither Business Systems nor Valuations have working relationships with the Surveyor General's Office or Deeds Office (see 5.3.2). Therefore, there is little to no communication between the Land Tenure System (LTS) and the CCT PMS, even though these systems are strongly related – the PMS is based on the cadastre that is the LTS's responsibility (see 6.3.5). Furthermore, the CCT departments are not notified of new or amended property RRRs and rely on manually checking their Surveyor General's Office and Deeds Office accounts (see 5.3.2). Business Systems are notified by CCT GIS users if an error in the land parcel dataset is found. Not having an automatic notification poses a risk of having out-of-date or incomplete LPO records in the CCT PMS, risking non-conformity with the GGPs and sustainable development goals (SDGs)(see 2.2.1, 3.1.4). Additionally, the Spatial Data Infrastructure Act (*SDI*, 2003) legally requires feedback and sharing between entities that work with the same datasets (see 5.5.2i). Therefore, both the LTS and the PMS are not fully complying with that Act.

7.1.2 SILOS ARE EVIDENT WITHIN THE CCT PMS

The CCT views city management as inherently spatial. It has therefore invested in GIS and built-up datasets and resources from comparatively early on (see Section 5.2). This is a valuable foundation that has immense potential and could be used as a basis from which to improve the system further. On the surface, the City technical systems seem to integrate well, using the unique LIS key to integrate property information across SAP, DAMS, GRM and the GIS (see Section 5.2). A holistic view of the property record is accessible via these platforms, as well as the internal and external viewers and libraries (see 5.2.5). These support decision-makers in providing significant amounts of information to stakeholders and the public. This conforms to the good governance principles (GGPs) by improving transparency, accessibility and public participation (see 3.1.4).

However, the CCT PMS can be broken into subsystems that align with the three land administration functions. Each of these have developed their own SDI that is specific to their function (see 2.2.3, 3.1.3, Section 5.2, Figure 5-4), effectively creating silo SDI's. The clear and relatively simple division of the parent diagram (Figure 5-5) into subsystem diagrams (Figure 5-6, Figure 5-7, Figure 5-8 and Figure 5-9) illustrates the independent nature of each PMS subsystem aligned to its function. Figure 5-4 presents a simplified representation of the flow of property information through the Property Value Chain. On the surface, it looks straightforward and effective; each Property Value Chain agent manages their part and passes it on to the next agent. However, the number of different data stores and their relationships become problematic – this is exacerbated by unique designs and workflows. This is not aligned with the Land Management Paradigm (LMP)(see 2.2.3, 3.1.3). For example, the Government Revenue Management system (GRM)(see Section 5.2) is completely independent of the other systems. It is only synchronising select, simplified datasets with SAP LUM, with no connection to the GIS (see Figure 5-2). This is concerning because the registered RRRs making up the LPO are captured by Business Systems into the GIS and by Valuations into GRM. These evident silos adversely affect sustainable development and the implementation of the GGPs (see 3.1.4).

Additionally, there are many sources of property information and, often, duplicate datasets. For example, the land use datasets are captured by Business Systems for Planning & Building Development Management (PBDM) and again by Valuations for their own purposes, using their own definitions, but effectively capturing the same information (see 5.3.3i, 5.3.3ii, 5.3.4ii). This is converse to the GGP of holding accurate property data and increases the risk of ambiguity or error in the records (see 2.2.2, 3.1.4). Furthermore, the SDI Act (*SDI*, 2003) requires collaboration and sharing between entities that use the same datasets (see 5.5.2i) as well as complete and up-to-date metadata (a lack of high-quality metadata has a large impact on the sharing of datasets (see 2.5.7)). It is apparent that there is little sharing or collaboration and a lack of metadata in the datasets (see 5.4.2). Therefore, the PMS subsystems are failing to adhere to the SDI Act too. However, it should be noted that datasets shared via the *Reporting geodatabase* are strictly controlled by Corporate GIS in line with the Act (see 5.2.4).

It is impressive how much data is shared internally and with the public and this should be applauded. However, as noted, there is much that could be improved upon. Datasets that are shared require extensive cleaning and alignment with CGIS requirements (see 5.4.1i). This discourages sharing of datasets. Those datasets that are shared are simplified to such an extent that their value is reduced. Furthermore, there are many datasets that are not shared at all – external parties have no knowledge of these, even though that information could be useful to them (see 5.4.1i). This can be attributed to a lack of communication and the silos that exist between the PMS agents. According to the LMP and the GGPs, property information should be accessible and exchangeable (see 3.1.3, 3.1.4) – this requirement is only being partly achieved within the CCT PMS.

7.1.3 THE CURRENT DEFINITION, USE AND MANAGEMENT OF THE PMO

The CCT holds a rich, varied and valuable amount of data on land and property that is managed well-enough to achieve the land administration goals to a certain extent (see Section 5.3). These data resources and the strong GIS foundation that the CCT has established, together have the potential to unlock the path to improved land administration and sustainable development in line with global standards and practices. This is within reach, however, the following issues have been identified in this research and would need to be addressed to realise this potential.

i DEFINING THE LPO IN THE CCT PMS IS INADEQUATE

A reliable digital record of the real property RRRs (LPO) does not exist in the Land Tenure System (LTS)(see 5.1.2i, 5.5.2i). The Surveyor General's Office and Deed's Office are responsible for recording real property rights in SA and are the primary custodians of land tenure. They should be responsible for all versions of the LPO, including a GIS record. However, the Surveyor General's Office GIS records have no legal weight and little care is given to the accuracy, consistency and standard of the data, leaving it an unreliable source of information(see 5.1.2i). This is contrary to the requirements of the GGPs and RRRs within the LMP – this can cause unnecessary confusion or conflict (see 2.2.2, Section 3.1).

Therefore, the CCT rightly choose not to adopt the Surveyor General's Office GIS records. Instead, the LPO data is captured off the diagram and the title deed by Business Systems and Valuations (see 5.3.2). This is a duplication of work, causing inefficient use of resources. As such this is contrary to the GGPs of an effective and efficient LAS (see 3.1.4). However, it is acknowledged the CCT has little other choice. The Surveyor General's Office diagram data is manually captured for entry into the GIS, risking human error (see 5.3.2i). SAP LUM automatically extracts the title deed data into a text format for Valuations, avoiding that risk (see 5.3.2ii). Ideally, the Surveyor General's Office and Deeds Office would maintain a single, reliable and up-to-date GIS. This would include all erven and registered limited real rights, as well as those that are approved but not registered. These records could be adopted by the CCT. This would remove any duplication of work and the risk of the CCT capturing incorrect, incomplete or inaccurate LPO data. It would additionally conform to the LMP, promoting sustainable development (see 3.1.3).

The CCT staff responsible for the GIS land parcel dataset and the property data captured into Government Revenue Management system (GRM), are neither registered land surveyors nor conveyancers and, therefore, do not have knowledge and experience in real property law (see 5.3.2). This may result in inaccurate property records within the CCT PMS, having detrimental effect on LPO records that play a large role in many aspects of City management. For example, Business Systems was not aware that limited real RRRs, such as servitudes, may carry height restrictions. Therefore, they do not currently capture that data into the CCT GIS (see 5.3.2i, 5.5.2i). This can have major knock-on effects because those heighted servitudes may affect development rights – the Property Value Chain will not be aware of that when making important decisions, adversely affecting the land administration functions and the achievement of the SDGs (see 2.2.1, 3.1.1,3.1.3).[53]

Furthermore, limited real RRRs that are created in the title deed alone are not captured by Valuations (see 5.4.2ii). Additionally, the data that is captured into the Government Revenue Management system (GRM) and SAP LUM is not georeferenced, but is reduced to attribute information (see 5.2.1, 5.5.2ii). That missing LPO data and spatial information has been shown to have the same disastrous impact as the missing servitude heights in the GIS.[54] The CCT therefore adopts incomplete information into their land parcel dataset that forms the foundation of the PMS and the PMO. A successful SDI, in line with the LMP, integrates all data types with the foundational cadastral record (see 3.1.3). It would be highly beneficial to the CCT to improve upon that LPO record that forms the basis of city management.

The shared land parcel dataset on the *Reporting geodatabase* is corrupted topologically by updates from SAP LUM and the *Master geodatabase*, a system-generated dataset, that overwrites the original, topologically-correct LPO data captured by Business Systems into the *Working geodatabase* (see 5.3.2iii). This is shown to result in serious topological errors within the dataset that may have wide-ranging effects within the land administration functions. To correct topological errors, a forced manual update is performed. However, not updating all land parcels creates further risk that new slivers may be introduced. This affects the accuracy and reliability of the dataset, converse to the GGPs (see 3.1.4). The *Working geodatabase* land parcel dataset is a valuable and accurate LPO record but it is unsuccessfully shared and consumed within the CCT PMS.

Furthermore, the land parcel dataset is an example of a dataset that does not have only one data source (see 5.2.4). The data is created in the *Working geodatabase* and shared via the *Reporting geodatabase*, but the *Reporting geodatabase* dataset is overwritten by SAP and the *Master geodatabase*, effectively creating a second record of the LPO (see 5.3.2iii). This speaks to the crux of the land parcel dataset issues: the land parcel dataset is the core base layer of the PMS – it should be compiled by a single team of professionals knowledgeable in property law. The *Working geodatabase* land parcel dataset should be the parent dataset due to its spatial nature and high-level of accuracy (see 5.3.2iii). However, the *Working geodatabase* is a constantly updated dataset and is not appropriate for sharing. Therefore, the solution could be to create the *Master geodatabase* as a copy of the *Working geodatabase* instead of a SAP system-generated dataset, and the SAP LUM data should be appended to that without overwriting the original spatial data that was captured by Business Systems. Currently, the work done in capturing the Surveyor General's Office records into the GIS is ineffectual because SAP LUM overwrites it before sharing takes place. This is inefficient and ineffective, contrary to the GGPs and the requirement for sustainable practices (see 2.2.1, 3.1.1, 3.1.4).

ii INADEQUATE COMPILATION OF THE PMO

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[53] Business Systems is currently investigating how to go about adding the height to the servitude feature class. It is challenging because that layer has a fixed schema that is difficult to change (see 5.5.1i).

[54] See *Appendix D*: Blouberg Beach Road case.

The property data recorded within the CCT PMS may or may not have spatial information embedded as it is common for geospatial data[55] to be recorded as attribute information tied to the LIS key, particularly in SAP and GRM (see Section 5.2, 5.5.2ii). This can be ascribed to the data being captured with only the primary purpose in mind; Valuations or Planning & Building Development Management (PBDM) do not typically need to know the spatial aspects of the property characteristics for their processes (see 5.5.2ii). This illustrates a lack of understanding of the true value of the data being collected and results in incomplete, disorganised or incorrect datasets. A lack of spatial information is problematic because property information is inherently spatial and by ignoring the spatial aspect of that data, much of the value and potential secondary uses for that dataset are lost. Additionally, this does not conform with the GGP of holding accurate and complete PMO data (see 3.1.4).

Moreover, there is a lack of credible spatial data of the underground infrastructure (see 5.5.2vii). The exact network position records are either unreliable, inaccurate or completely unknown. This data is essential for successful and sustainable urban management, including the land development approvals (see 6.2.1). This data could be captured from approved wayleaves that are required for laying or maintaining these networks. However, this is not being done and is a major data collection opportunity loss, resulting in incomplete PMO data that can have detrimental effects on urban land management and sustainability (see 3.1.3, 3.1.4).

Furthermore, there is no kerbline dataset that could be used to derive the positions of underground utilities. The missing kerbline dataset likewise has an impact on the 3D development envelope compilation as the CCT has to resort to using the road centreline dataset that is an inaccurate record of the road infrastructure (see 5.3.3ii). Therefore, the calculated development envelopes that are used in daily PBDM processes and decision-making are partly based on an erroneous data source, affecting the success of land use and development functions (see 3.1.3).

iii NON-UNIFORM DEFINITIONS AND WORKFLOWS

There are misalignments between different departmental definitions and workflows. Valuations capture land use data to a floor-level LOD and using more detailed land use definitions than those found in the Development Management Scheme (DMS) and used by PBDM (see 5.3.4ii, 5.4.1i). Therefore, these datasets do not align and cannot be easily compared or combined; converse to the GGPs (see 3.1.4). Furthermore, this dataset is not shared outside of Valuations (see 5.2.3), even though it could be extremely useful to others; this LOD could be used to query how much of a building is used for each land use.

Valuations not only inherits PMO data from the other Property Value Chain agents, but captures primary PMO data too, including overlapping datasets such as the real property RRRs and land use datasets (see 5.4.2, 5.3.4ii). This results in a duplication of efforts, a risk of misaligned datasets and a waste of resources. This inefficiency is unsustainable and ineffective, contrary to the GGPs and LMP (see 3.1.3, 3.1.4) and should be addressed by combined efforts across departments and specialisations.

iv CUSTOMIZATION PREVENTS UPGRADES

The CCT has introduced a number of custom modifications into the technical systems to achieve their land administration goals (see 5.4.1i). The sheer number and complexity of these customisations prevent the CCT from doing simple system upgrades, for example, including heights in the servitude dataset, let alone any major

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[55] See *Appendix A.*

overhauls that may be necessary to achieve the goals of land administration and implement the GGPs (see Section 3.1). The LAS should be more adaptable to face the current and future urban complexity (see 2.2.2).

v LACK OF RESPONSIBILITY FOR SHARED RESOURCES

Both the internal and external viewers carry a disclaimer that waives all responsibility of maintaining a reliable, consistent, and up-to-date GIS (see 5.4.1ii). In the same way that the Surveyor General's Office does not take responsibility for the digital cadastral records, the CCT waives their responsibilities for their shared datasets. This is highly problematic because many of these datasets, such as the zoning layer, are the only information source of that information type with the CCT being the creator and custodian of that dataset. As there is no other source, it cannot afford to be incorrect or corrupted, but the CCT waives that responsibility. PBDM make use of the zoning dataset for decision-making and, if it is incorrect, there is no way to identify the correct zoning (see 5.4.1ii). To fully move into a digital era, all LAS agents should fully commit to maintaining the highest possible standard in the PMO datasets for which they are responsible, as required by the LMP (see**Error! Reference source not found.**, 3.1.4).

7.1.4 ACHIEVING THE LAND USE FUNCTION

The context and impact of each Land Use Management (LUM) proposal should be adequately assessed by all stakeholders to successfully achieve the land use function. Digital plans are submitted and accessed via DAMS (see 5.3.3i, Figure 5-7). However, LUM staff have acknowledged it is challenging to interpret complex 2D plans digitally and the plans are often printed out (see 5.4.1ii). This negates the paperless-drive that was motivation for introducing DAMS, reduces effectiveness and efficiency, and is contrary to the GGPs (see 3.1.4). In the case of an objection, the case is referred to the Municipal Planning Tribunal. This Tribunal faces challenges of making typically complex and controversial land use decisions in an exceptionally short amount of time and with inadequate, inaccessible data (see 5.3.3i). The Tribunal do not have access to the detailed property records or CCT systems and relies completely on the evidence presented to them. Therefore, the context and impact of each of these cases are not adequately assessed. Therefore, the land use administration function may not be fully achieved in CCT and this could be improved upon.

The Development Management Scheme (DMS) rules defining the development envelope are overly complex, especially with regards to the various height definitions, making it difficult to objectively apply the rules (see 5.5.2iv, 6.1.1ii). Furthermore, the DMS rules have setback and height implications that define the volume of the development envelope, but these rules are not captured or represented in 2D or 3D. Rather, a zone code is attributed to each land parcel in the CCT (see 5.3.3ii). It is then up to the interested party or decision-maker to decipher the rules applied to that erf. This is highly problematic, because it leaves room for a subjective interpretation of the DMS, which is already unclear, and assumes people have good spatial understanding, which is typically not the case. The true implications of the DMS may be misconstrued and Planning & Building Development Management (PBDM) decisions may be adversely affected. A lack of understanding of the DMS leads to more objections and therefore, more Tribunal cases (see 5.5.2iv). This leads to inefficiency and ineffectiveness in the LUM processes, converse to the GGPs and LMP (see 3.1.3, 3.1.4). Often, these are cases that may not have resulted in objections if all stakeholders were properly informed.

Furthermore, Business Systems is responsible for the zoning dataset, but LUM makes the zoning decisions (see 5.3.3i, Figure 5-7). LUM notifies Business Systems of all decisions made, but there is room for error in this process.

Furthermore, the Business Systems custodians (not being planning professionals) may lack a full understanding of the DMS and the application thereof, increasing the risk of incorrect or inadequate record-keeping that is contrary to the LMP requirements (see **Error! Reference source not found.**). The decision-maker / policymaker should be the responsible party and custodian of that dataset that determines development RRRs across the CCT, as well as being a registered planning professional.

Finally, the LUM processes are found to be unnecessarily complex, time-consuming and expensive (see 5.5.2iv) – this is not aligned with the LMP or GGPs (see **Error! Reference source not found.**, 3.1.4). This has led to an increase in illegal land use and developments occurring in the CCT; the public would rather pay an administration fee than attempt to engage with the current application process. This adversely affects the CCT's PMS because the CCT does not know about and cannot control the land uses and developments being implemented. Thus, the PMO record may be inaccurate. This is impossible to correct; the only solution is to simplify the processes and make them more accessible, removing barriers for the public to participate and communicate with the CCT.

It can be concluded that the land use function is not fully achieved and could be improved upon.

7.1.5 ACHIEVING THE LAND DEVELOPMENT FUNCTION

The application documents submitted into DAMS are 2D scanned copies of building plans, including individual floor plans (see 5.3.3iii, Figure 5-7). These plans are stored in SAP LUM, attached to the LIS key, but no spatial information is extracted from them. This may be an opportunity wasted to acquire valuable data on all new CCT developments. Moreover, as in Land Use Management (LUM), the submitted building plans are acknowledged as being difficult to interpret digitally and, therefore, are often printed out. This shows again how the current PMS fails at its goals to be paperless and more efficient in line with the GGPs (see **Error! Reference source not found.**). Furthermore, the PMO LOD recorded in PBDM is insufficient for Building Development Management (BDM) processes (see 5.5.2v), resulting in an inadequate achievement of the land development goals. Additionally, the LUM approval notification (see Figure 5-7) is not effectively communicated to BDM; BDM typically has to investigate this at the offset of an application (see 5.3.3i, 5.5.2v). This illustrates a lack of continuity and transparency within the Property Value Chain.

The public can object to a LUM application but not to a BDM application – there is no BDM appeals authority. If a development falls within its allowable development envelope, there is no need for a LUM application, leaving the public with no way to comment other than appealing to the court (see 5.3.3i). Therefore, it is vital that the public are well-informed during the LUM processes – this is currently not the case as illustrated by the high number of objections dealt with by the LUM officials and the Tribunal. The missing recourse opportunity for the public in the BDM processes seems to be an important oversight; this excludes the public from the BDM processes and is contrary to the GGPs (see **Error! Reference source not found.**).

It can be concluded that the land development function is not fully realised and could be improved upon.

7.1.6 ACHIEVING THE LAND VALUE FUNCTION

Field valuation surveys yield the most accurate valuations but are resource-hungry, expensive and access is often an issue (see 5.3.4i). In-office surveys are time and resource efficient but cannot produce the same data quality (see 5.3.4i). A middle ground is needed between the two methods of data collection that allows for more detailed data to be drawn from remote survey techniques to increase the efficiency and effectiveness of the Valuations department, to conform with the GGPs and attain successful implementation of the land administration functions (see **Error! Reference source not found.**).

The property data collected by Valuations and captured into GRM is detailed and highly valuable. However, it is not spatially defined; the information is captured as attribute data tied to each property's LIS key (see 5.2.4, 5.3.4ii). Nevertheless, the types of information collected include land use, access, security, neighbourhood character, noise, views, and floor area, all of which have spatial meaning. Therefore, this information is spatially relevant as it describes a property object and therefore, adds value to the PMO (see Figure 6-1). Unfortunately, that value is unavailable meaning that the potential uses for the datasets are reduced significantly. Furthermore, the LMP and GGP require the PMO to hold comprehensive property data (see 3.1.3, 3.1.4) – this is shown to not be the case.

Therefore, the land value function is achieved successfully, but it could potentially be improved upon.

7.1.7 IN CONCLUSION: IMPROVEMENTS TO THE CCT PMS COULD BE IMPLEMENTED TO BETTER ACHIEVE THE LAND ADMINISTRATION GOALS

Sustainable development is the principal goal of the LAS and requires informed decision-making, accountable governance and public participation, in line with the good governance principles (GGPs)(see 3.1.1, 3.1.4). The RRRs should be delivered holistically through the successful implementation of the land administration functions to achieve sustainable development in the face of urbanisation (see 2.2.1, 3.1.1). Each land administration function of the LAS can be achieved individually (see 3.1.3) and, within the SA LAS, there are evident silos created between the subsystems associated with those functions (see 7.1.1, 7.1.2). This issue could be seen as a major opportunity for change, to centralize the information system, expand sharing capabilities and improve workflows.

Governance is qualified as good if it achieves the GGPs that promote effective land administration (see 3.1.4). Furthermore, property information should be comprehensive, accessible, exchangeable and timely according to the LMP (see 3.1.1, 3.1.3). However, in terms of good governance, the PMS is only partially successful and the PMO does not fully adhere to the LMP requirements. Within the CCT PMS, the PMO:

- is often duplicated, as shown by the various subsystems who record the same information,
- is not comprehensive or accurate as it often lacks geospatial meaning or is collected with only the primary purpose in mind, effectively ignoring valuable detail,
- is inaccessible, as shown by the evident silos and the lack of shared meaningful property data,
- is not exchangeable, as the PMS lacks standardisation of consistent land use definitions and policies within the PMS subsystems,
- is not transparent, as evident in the complex PBDM processes that the public avoid, and in the lack of understanding or communication between the various Property Value Chain agents,
- is unsustainable due to the inefficiency caused by inaccurate, incomplete, duplicated and inaccessible PMO data that will become more complex as urbanisation sees densification increase,
- and is purpose-driven rather than user-driven as shown by the various departments only recording data that is necessary to their purposes, rather than considering the variety of uses to which that data could be put.

Therefore, this research has shown that the current CCT PMS could improve on its efficiency and effectiveness if the following important inherent issues were to be addressed: the most valuable data is not shared, some datasets are duplicated, there is a lack of sufficient metadata and the various departments producing and managing PMO data do not collaborate, share or communicate sufficiently. One can generalize that there may be issues of data integration and sharing across the CCT, outside the PMS, based on the results of this research. These issues indicate the CCT PMS could improve upon achieving the GGPs of public participation, sustainability, efficiency and effectiveness, transparency, and a comprehensive, accurate and timely PMO record (see 3.1.4). Therefore, the CCT PMS has been shown in Section 7.1 to be limited with regards to the use, management and sharing of the PMO and the successful achievement of all of the land administration goals related to land use, development and valuation.

Section 7.2 The Potential Impact of Introducing 3D on the CCT PMS

It is acknowledged that introducing 3D into the LAS as a whole can improve land administration, decision-making and forecasting (see Section 2.3). The land administration functions are inherently 3D and involve more property information than is available within only the cadastral layer. Therefore, introducing 3D should include the integration of the Legal Property Object (LPO) with all other property information, whether spatial or attribute data, creating the Property Management Object (PMO). There are many 3D use cases that have been identified in published research (see Section 2.4). However, the usefulness of 2D property data versus a 3D PMO is shown to be task-related within local government processes (see 2.4.1iii). The following section will delve into the benefits and challenges that 3D may introduce, according to the results presented in this research. The coherence of the data presented in Chapter 6 and linked to international experiences as presented in Chapter 2 shows strong internal validity. Outlier responses are acknowledged and dealt with in a weighting scheme. Similarly, reliability was shown by the alignment of the data collected via a multitude of sources (in-depth interviews, personal work experience and documentation including organisation structures, workflows and policies) on the CCT PMS.

7.2.1 THE CURRENT USE OF 3D IN THE CCT PROPERTY MANAGEMENT SYSTEM

The capture of 3D building models and development envelopes is too slow to be truly effective and is limited to key interest areas (see 6.1.1). Although these 3D models have been shown to be useful in certain applications (see Section 6.1), the limited number and coverage of the models reduces the potential uses of the 3D environment. To speed up 3D data acquisition, the LOD could be reduced to attain a full city dataset that can then be improved upon through further primary data capture and by requiring submission of 3D models with complex Planning & Building Development Management (PBDM) applications.

A number of problems have been highlighted with regards to the 3D development envelope models (see 6.1.1ii, 7.1.4):

- the DMS is too complex for clear understanding,
- there are multiple ways to define existing ground level,
- the land parcel dataset has topological errors,
- the zoning dataset has been found to be out-of-date at times and is not a spatial-record,
- and the current 3D models are static in time, reducing their use and relevance.

These issues reduce the quality, accuracy, relevance and completeness of any 3D development envelopes that are modelled – this is a situation that should be addressed. The proposed Ground Level Map is an attempt to simplify the definition of existing ground level (see 6.1.5).

Business Systems record the sectional title building footprint into the GIS and attribute it with the floor heights recorded in the sectional title plans (see 5.3.2i). This is a valuable dataset, although it is not 3D and is not broken down into unit level. However, it indicates that some departments are thinking about capturing data to a higher LOD and it is one step closer to a 3D PMO.

7.2.2 ACHIEVING THE CCT URBAN VISION

The CCT policies and strategies for development (see 5.1.4) require spatial transformation in the form of extensive densification to cope with the expected population growth and to avoid unsustainable sprawl (see 2.2.1). This will result in overlapping and interlocking PMOs in an increasingly complex City that requires up-to-date, accurate and complete property records (see 2.2.2). Introducing 3D is acknowledged as being critical to improving the LAS to cope with these challenges, successfully implement policy, and become multipurpose in its functioning (see Section 2.3, 6.2.1, 6.2.4, 6.2.5). A 3D PMO record can aid evidence-based planning and policy development (see 2.4.1ii, 6.2.4). The CCT have started to use 3D to better understand and plan for the changing urban environment (see Section 6.1).

CCT policy requires the identification of underutilised development opportunities and an analysis of development patterns (see 5.1.4, 6.2.4). These are inherently volumetric analyses that are already employed in select, enterprising departments (see 6.1.3). This analysis cannot be accurately achieved in 2D where the verticality of possible development is ignored. 3D is recommended for visualisation of long-term policy determination (see 2.4.1ii). Therefore, the DMS should be visualised in 3D as development envelopes. This dataset can likewise be used to analyse the long-term impact of the DMS rules and evaluate whether it will have the effects that CCT policy requires (see 2.4.1ii, 6.2.4)(see the example in 6.1.1ii). A spatial understanding of this impact is important for achieving the Spatial Development Framework (see 6.1.3, 6.2.5). Furthermore, having a 3D visualisation of the CCT development policies available to all stakeholders, increases the accessibility and acceptability of those policies (see 2.4.1ii, 6.2.4).

Additionally, the publishing of a 3D PMO dataset, that includes the 3D development envelope dataset, would create a more-informed public, hopefully reducing objections and conflict situations, and may result in stimulation of the property and construction markets and thus the local economy (see 2.4.1iv, 2.4.5, 6.2.2). The CCT does not attract sufficient investment to attain its densification goals, even with development incentivisations (see 5.1.4, 6.2.4). Accessible information on the built environment and the potential development RRRs in 3D may inform buyers, support accurate infrastructure planning, and stimulate the local property market (see 6.2.4, 6.2.9); this would assist in achieving the CCT's policies. Moreover, the predictions and planning for future infrastructure and utilities may be more accurate when employing 3D data (see 6.2.4).

7.2.3 IMPROVED INFORMATION MANAGEMENT AND BROADER ANALYTICS

A 3D city model offers a rounded approach to managing property data that would support data integration and across-specialisation collaboration and decision-making in the CCT (see 2.4.1, 2.5.6, 6.2.5, 6.2.6). This would improve the clarity, accuracy, security and reliability of the property records and support more informed decision-making and policy definition (see 2.4.1). Furthermore, a 3D environment encourages a higher LOD that would support the separation of property objects from the surface parcel to improve CCT property management including land use, development and value (see 6.2.5). Additionally, datasets that are inherently 3D, such as heighted servitudes, that often have a direct effect on the use of property, are best understood in a 3D environment (see 2.4.1, 6.2.9).

i BROADER ANALYTIC CAPABILITIES

The integration of different datasets (for example, utilities consumption) into a 3D geospatial environment creates further opportunity for in-depth analytics that may be more accurate because of the inclusion of the third dimension (see 2.4.2, 6.2.6, 6.2.9). The true spatial patterns of phenomena (for example, flooding impacts) can be better understood as 3D is a closer representation of reality than 2D maps, allowing for heighted and/or volumetric analyses.

There is an abundance of literature published on the analytics that are possible when employing 3D data, many of which may be useful to the CCT, such as modelling of future energy demands[56] (see 2.4.2). The enhanced analysis options are better for estimating future population needs to inform planning and policy. These are seen as beneficial to adequately coping with the effects of climate change and promoting sustainable development (see 2.4.2). A 3D GIS is identified as useful to analyse crime and improve security and public safety (see 2.4.2). This is highly relevant in the CCT where public safety is topical. Furthermore, CCT policy recognises the importance of conducting environmental impact analyses of proposed developments which deal with inherently 3D characteristics such as energy consumption or heat and noise insulation (see 2.4.2, 5.1.4, 6.2.6). Select departments within the CCT have made use of this type of analysis in an elementary form and the use is recognised (see 6.1.4), however the current systematic and data silos that exist are holding back progress in this area (see 7.1.2).

ii IMPROVED INFRASTRUCTURE MANAGEMENT

CCT has recognised that a 3D record of the utility networks and infrastructure is highly valuable, as these are inherently 3D and should be managed in 3D (see 2.4.3, 6.2.7). A 3D model could allow for the analysis of both the coverage and the potential of these networks, as well as predicting and planning for future infrastructure requirements (see 2.4.2, 2.4.3). It is accepted that 3D utility records reduce the inefficiencies, costs and risks associated with infrastructure management (see 2.4.3). Additionally, it is important for the CCT to capture the 3D road and kerb datasets to allow for more accurate mapping of underground utilities and modelling of the DMS development envelopes (see 5.3.3ii, 6.2.7, 7.1.3ii).

7.2.4 THE LAND USE AND DEVELOPMENT NEED FOR 3D

The CCT has acknowledged increasing spatial complexity by adopting new policies to manage new property objects and protect valued cultural and natural resources, for example, the Scenic Drive Management Plan (see 2.2.2, 5.3.3ii). Land use and development proposals are inherently 3D in character and should be dealt with as such (see 2.4.1iii, 5.3.3, 6.2.1). Building Development Management (BDM) have acknowledged that a full 3D city model, including the kerb and utility datasets, would be very useful to their processes (see 6.2.1).

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[56] South Africa is in an energy crisis. The more accurate current and future energy demand analysis that 3D is thought to allow, may provide the CCT with the much needed information to deal with this crisis.

i IMPROVED PLANNING & BUILDING DEVELOPMENT MANAGEMENT VISUALISATION

3D visualisations present a relatable and understandable perspective that is useful when dealing with complex environments (see 2.4.1, 6.2.3). The proposal plans submitted via DAMS for land use and development applications are difficult to understand in the current 2D digital format (see 5.3.3i, 5.4.1ii). This will worsen as urban environments become increasingly complex (see 2.2.2). A 3D city model, including the development envelopes, can provide improved analysis of the context, height and bulk of a proposal, allowing for visual impact analysis to aid informed decision-making (see 2.4.1, 6.2.1, 6.2.3). The context and potential impact of a development is becoming increasingly important to analyse. It is noted that 3D would be highly beneficial to the Municipal Planning Tribunal's processes, increasing the timeliness and reliability of their decisions (see 5.3.3i, 6.2.1, 7.1.4). If land use and development proposals could be automatically checked in 3D, this would potentially remove some of the risk of subjectivity, corruption and human error in Property Value Chain processes (see 6.2.1).

The 2D development plans hold much valuable information that could be extracted into the CCT records and, rather than only storing the plans attached to the LIS key, a 3D model could be required from applicants to assist decision-makers. in particular, this could be applied to complex cases that will be seen more often as urban density increases (see 2.2.2). If this model is dropped into a 3D environment, the assessment could be far more interactive, efficient and effective, aligning with the good governance principles (GGPs), and thereby improving decision-making processes and promoting communication as required for sustainable development (see 2.4.1, 3.1.3, 3.1.4, 6.2.1). This further aids the avoidance of misunderstandings and the potential for conflict (see 2.4.1iv, 6.2.2). Furthermore, 3D information is identified as useful to protect precious urban spaces and resources (see 2.4.1ii). This is in line with the LMP (see 3.1.3) – 3D visualisations are currently used on an ad hoc basis for these analyses (see 6.1.2).

ii THE DEVELOPMENT MANAGEMENT SCHEME NEED FOR 3D

The Development Management Scheme (DMS) zoning rules define the RRRs volume attached to a land parcel, forming an important part of the PMO definition. Therefore, this should be represented spatially, in 3D, for adequate decision-making and to improve public participation and information-sharing (see 6.2.3). Visualising a single erf's development envelope is challenging on its own, let alone attempting to visualise an area or the whole City in one's mind's eye. This employment of the imagination is currently necessary in the CCT 2D GIS because the zoning information is only captured as an attribute attached to a land parcel (see 5.3.3ii). This is highly problematic. The zoning layer should be spatially defined; users should be able to turn the spatial meaning of that zone as applied to that property on and off to *see* the implications of that zone. A 3D environment makes the DMS more accessible and understandable, reducing the risk of misunderstandings or conflict (see 2.4.1).

To achieve an adequate 3D record of the DMS rules, the input datasets should be of the highest quality. The erf shape and area, the zone, road centrelines and existing ground levels are some of the important data that contribute to defining the development envelope and therefore, the PMO (see 5.3.3ii). The land parcel dataset should be of the highest quality as it is the foundational layer of the LAS (see **Error! Reference source not found.**), while the CCT should capture the kerblines to correctly define the road centreline (and not interpolate it from cadastral records). Furthermore, the DMS rules are too complex and flexible (see 5.3.3ii, 5.5.2iv, 6.3.1), making objective modelling difficult, if not impossible. The DMS requires significant simplification and clarification. For example, there should be one simple, unambiguous definition of the existing ground level that is applied to the definition of the development envelope.

iii THE NATIONAL BUILDING REGULATIONS ACT NEED FOR 3D

The subjective nature of analysing a proposed development in terms of Section 7 of the National Building Regulations Act (1977) is the cause of much concern within the Building Development Management (BDM) department (see 5.3.3i, 5.5.2v). It is not within the scope of this research to comment on the controversial aspects of this Act. However, a 3D PMO may assist the BDM officials to reduce subjective interpretations of the effect of a proposed development on a neighbourhood character, for example, by providing a more realistic visualisation that the official can interact with and analyse. Currently, BDM officials have to make these decisions using 2D building plans. Furthermore, Section 7 requires an official to decide whether the proposal will decrease the values of the surrounding properties (see 5.3.3i). This should require consultation with Valuations, being responsible for the land value administration goal.

7.2.5 THE PROPERTY VALUATIONS NEED FOR 3D

The property information necessary to the Valuations processes is highly detailed and should be comprehensive and up-to-date to ensure a fair and accurate valuation. Accurate and up-to-date property records allow for improved land taxation, which is fundamental to achieving the other land administration goals, because of the municipal income it generates (see 2.4.4, 5.3.4, 6.2.8). However, it may become difficult to maintain and analyse the characteristics of property objects in the current 2D system under circumstances of fast-growing, complex urban spaces. A 3D city model that includes a higher LOD (property object level) is seen by some as a recommended route for improving the land value function (see 6.2.8). The literature shows that a 3D environment results in more accurate and inclusive valuations processes, including in mass appraisals. For this reason, some municipalities have already made the move to 3D for valuations (see 2.4.4).

Currently, the data captured by Valuations into the Government Revenue Management system (GRM) is not spatially referenced (see 5.3.4ii, 6.2.8). There are specific value-adding property characteristics that influence the value calculated including, but not limited to, floor area, the number of rooms, access and security, the neighbourhood character, environmental noise, topography, views and, importantly, the use of the property. These aspects, bar the floor area, are related to the 3D position of the property in its environment and cannot be accurately assessed on a 2D plan or using oblique imagery (see 2.4.4, 5.3.4ii, 6.2.8). In particular, the valuations process ranks views and the level of security highly, but these are extremely difficult to determine without access into the property itself. Regarding the floor area, it is noted that the usable volume would be a more accurate figure for some properties, for example, industrial or sectional title properties (see 2.4.4, 5.5.2vi, 6.2.8). Having a 3D city model could improve the in-office valuation process, saving the CCT time and resources that it usually expends on field surveys. Whether the income generated from more accurate valuations and the time and resources saved will balance the expense of introducing a 3D city model is yet to be established. Importantly, valuations datasets are only useful if they are up-to-date and of a significant LOD (see 6.2.8). This becomes crucial when considering introducing 3D city models; how will the CCT Property Management System (PMS) maintain and manage an up-to-date, accurate and detailed 3D city model of the CCT (see 6.3.3)?

7.2.6 3D SUPPORTS IMPROVED COMMUNICATION

Public engagement and participation is improved by 3D city models and visualisations as it provides a relatable perspective that is easier to understand (see 2.4.1ii, 2.4.1iv, 2.4.2, 6.2.2). It is likely that a broader audience could be reached using 3D and employing a more interactive format than static 2D plans, effectively democratising the PMO and Property Value Chain processes (see 2.4.1iv). It has been found that members of the public do find 3D easier to understand and grasp the consequences of proposals or phenomena (see 2.4.1ii, 2.4.1iv, 2.4.2). An informed public is less likely to object to change because of their uncertainty, and it is likely the number of Planning & Building Development Management (PBDM) objections would decrease, improving the efficiency of the processes. This would support the implementation of the GGPs that promote efficient and effective LAS that engages the public and is user-orientated (see **Error! Reference source not found.**). Furthermore, 3D models may aid conflict resolution and have been successfully used by the CCT in litigation (see 6.2.2).

7.2.7 CONCERNS AROUND INTRODUCING 3D

i THE INSTITUTIONAL CHALLENGES AND A LACK OF RESOURCES

Introducing any new system requires significant change management. 3D city models introduce a new paradigm for understanding property, not only a new way of working, so it will be that much more challenging (see 2.5.1, 6.3.2). It is difficult to motivate changing something that is seen to work adequately, especially when it is difficult to illustrate the benefits prior to the system being introduced. Initially, all change brings about a frustrating adaption period (see 2.5.1) and, if not well-communicated, the changes can result in staff, stakeholder and public angst (see 6.3.2).

A 3D city model would be extremely expensive to build and maintain (see 2.5.5, 6.3.6), and would require significant skills, resources and capacity (see 2.5.1). Maintenance is seen as one of the greatest challenges (see 2.5.3). It is noted that the computational costs of working in 3D are far higher than that of a 2D GIS environment (see 2.5.5). Unfortunately, the CCT struggles with limited financial, technical, capacity and skills resources (see 6.3.3). The research and development necessary to implement 3D into the PMS would require major investment in these areas (see 2.5.5), amongst others, and to attract that investment the project would require significant buy-in from stakeholders, politicians and upper-level management (see 6.3.2). To gain the confidence of stakeholders it is imperative to show that the benefits are significant when compared to the costs (see 2.5.1), but this is next to impossible when no city in the world has a fully operative 3D city model as yet (see 6.3.6).

The existing information silos and the lack of collaboration within the CCT is highly problematic for introducing a 3D city model that requires integration and interoperability across specialisations and between government, business and the public (see 2.5.6, 6.3.1, 6.3.5). Silos originating from incompatible datasets, inconsistent data management, varying definitions and a lack of communication are a major challenge for introducing 3D into LAS (see 2.5.6). Standardisation is imperative to support data integration and interoperability. Furthermore, there is a lack of compatibility in the current CCT technical systems used by the various Property Value Chain departments that is problematic for introducing 3D models (see 2.5.6, 6.3.8). Making changes to the existing IS&T infrastructure is seen as highly challenging and expensive (see 2.5.4, 2.5.5). Furthermore, it is acknowledged that the IS&T department is an important stakeholder when implementing a change such as this (see 6.3.5).

There does not currently exist a 3D city model anywhere in the world that has successfully implemented a combined LPO-PMO solution, but a 3D solution should integrate these datasets to be truly useful (see 2.5.2). There is likewise no technical solution to combine these two disparate datasets. Additionally, there is currently no means, or support, within the CCT for serving those 3D datasets that do exist and there are limited available software options (see 2.5.4, 6.3.8). Furthermore, there are limited, adequate 3D analysis tools currently available, while 3D analysis is seen as one of the major benefits of introducing a 3D environment (see 2.5.4).

ii DATA QUALITY CONCERNS

A 3D city model is only as useful and accurate as the quality of the datasets captured in it; the data quality affects the integrity and sharing of the datasets (see 2.5.7). It requires topologically correct and up-to-date datasets (see 6.3.1), especially the foundational datasets that include the land parcels, 3D building models, DEM and 3D development envelopes. The LOD of these datasets is currently insufficient to support 3D and would need to be increased across the whole CCT PMS (see 2.5.4). The lack of capacity is a problem here because the CCT has not been able to produce a full LOD1 building footprint dataset as yet, let alone moving to higher LODs (see 6.3.3). It is recommended that different LODs be adopted for different purposes (see 2.5.6), but this should be standardized and applied across the CCT. Moreover, a 3D environment requires up-to-date datasets and the CCT does not successfully maintain the current 2D datasets, let alone a more detailed 3D version (see 2.5.3, 6.3.3). Furthermore, to gain the full benefits of a 3D environment, the geospatial datasets should be consistently integrated with as many other different types of data possible (see 2.5.4). Any information can be linked to an object, but the CCT do not currently have the objects due to a lack in capacity to build up these datasets; the technical, human and financial resources do not exist to carry out this project.

Furthermore, the real property RRRs layers cannot be directly adopted from the Surveyor General's Office or Deeds Office and are incomplete and inaccurate; as discussed in detail in 7.1.3. Furthermore, the topological errors present in the shared land parcel dataset (see 5.3.2iii) become more pronounced when moving into a 3D environment, adversely affecting the data quality. Data validation in 3D is far more complex and computationally draining than 2D validation, and there is a lack of research into 3D object validation (see 2.5.5, 2.5.7). Additionally, the missing limited real RRRs data is highly problematic (see 5.3.2, 7.1.3i) as these can have huge implications for land use, development and valuations decisions, as well as for policy-makers. [57]

As mentioned in 7.2.4ii, the Development Management Scheme (DMS) is overly complex and the rules are subject to interpretation, not lending themselves to easy modelling or automation (see 5.3.3ii, 5.5.2iv, 6.3.1). This is problematic when moving into a 3D environment. Furthermore, to move into a 3D environment, the existing ground level should be fixed as a reference surface. The CCT is moving in that direction with the proposed introduction of the Ground Level Map (see 6.1.5) but for now it is only one of the several optional definitions. This increases the risk of confusion, ambiguity and the subjective application of the DMS rules, increasing inefficiency in the PBDM processes. Additionally, the development proposal plans submitted to PBDM are often outdated, incorrect or simplified (see 6.3.1) and, therefore, unusable for accurate 3D modelling.

iii THE ACCESSIBILITY AND RELIABILITY OF 3D

A 3D city model can be deceptively realistic and appear trustworthy, and therefore, could be used to sway opinion or manipulate decisions (see 2.5.8, 6.3.4). Issues of occlusion and perspective are not easily identified by users not familiar with the platform or the scene being presented (see 2.5.8). A lower LOD is better for public representation, because it avoids the distraction caused by too much detail (see 2.5.8).

The Planning & Building Development Management (PBDM) processes are already time-consuming, expensive and complex (see 5.5.2iv) and it is thought 3D may escalate this. Furthermore, a 3D solution should be publically accessible and user-friendly to be successful. An unintended result of introducing 3D may be the exclusion of

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[57] See *Appendix D: Blouberg Beach Road case*.

disadvantaged groups (see 2.5.9, 6.3.7). Land policy should provide for disadvantaged and minority groups (see 3.1.2). Introducing 3D does pose a risk of excluding these groups by creating a technocratic solution that is inaccessible to most, possibly resulting in segregation, gentrification and the entrenchment of apartheid spatial designs (see 6.3.7).

There is concern that in some cases, or even most cases, a 3D PMO is not valid and does not increase the understanding or accessibility of that information. In other words, the PMO presents too much detail in cases where the property is simple and understandable in 2D. This would be converse to the LMP requirements for the PMO to be valid and accessible (see 3.1.3). Furthermore, there are ethical concerns that a higher LOD in a 3D environment poses risks of data protection, terrorism and cyber-crime (see 2.5.10), and specifically within the CCT an additional risk to the security of data and physical infrastructure (see 6.3.9).

7.2.8 IN CONCLUSION: THE POTENTIAL USES, BENEFITS AND LIMITATIONS OF INTRODUCING 3D INTO THE CCT PMS

The CCT have started to make use of the 3D property information available to them, albeit on an ad hoc basis, and this has allowed some to recognise the potential benefits that 3D may offer. It is recognised that an effective RRRs record system has broad societal benefits (see 2.2.2) and that increasing urbanisation is leading to a more complex and diverse environment that requires up-to-date, comprehensive and accessible records to improve land administration and achieve sustainable development (see 2.2.2). A multipurpose cadastre in an integrated SDI supports the LAS and its four land administration functions, as well as improving public participation, data integration, quality and accessibility, analysis capabilities, transparency and e-governance; this is in line with the GGPs (see 2.2.4, Section 3.1). Furthermore, a multipurpose cadastre promotes the use of 3D and smart cities to improve the LAS (see 2.2.4).

A 3D city model is seen as the answer to the increasing complexity and diversity within cities world-wide (see Section 2.3); a conclusion confirmed in this research. Introducing 3D into the CCT PMS could assist with achieving the GGPs and the goal of sustainable development (see Section 2.3, 3.1.4), because 3D:

- supports informed decision-making, evidence-based planning and policy development,
- improves the clarity, accuracy, completeness and reliability of the property records,
- aids the removal of silos by supporting data integration, transparency and across-specialisation collaboration,
- offers more in-depth and varied analysis capabilities of different phenomena that are impossible or inadequately analysed in 2D,
- promotes a better understanding and management of inherently 3D datasets such as the development envelopes or utility networks,
- presents a relatable and understandable perspective in visualisations to aid informed decision-making,
- supports more accurate and fair valuations processes,
- improves public participation and information-sharing, due to the relatable perspective that is easier to understand,
- and improves the efficiency and effectivity of the Property Value Chain processes in land use, development and valuations.

However, a 3D city model is only as valuable as the variation and detail of the datasets included in the model and the accessibility and quality of that data. The existing information silos and the lack of collaboration within the CCT, as well as the questionable data quality of the core PMO datasets, are problematic. Furthermore, it is noted there are limited technical solutions to implementing a 3D city model. It would be expensive to build and maintain and would require significant investment into skills, resources and capacity; funds that the CCT currently does not have. Any 3D solution should be accessible, affordable and user-driven. If it does not benefit the stakeholders, including the CCT, it is of no value. A full cost-benefit analysis is recommended to establish the value-gain.

In conclusion, the potential benefits of introducing 3D into the PMS are significant and, although there are numerous challenges that would be faced, the PMO and land administration is inherently 3D, and city management would benefit from adopting a 3D city model.

Chapter 8 CONCLUSIONS AND RECOMMENDATIONS

This study attempts to answer whether a 3D LAS is needed in the South African context. To this purpose, the research delves into the current state of the CCT Property Management System (PMS) with respect to the Property Management Object (PMO) and its ability to successfully achieve the land administration functions of land use, development and value. The potential uses, benefits and challenges of introducing 3D into the PMS are presented, as drawn from interviews with key CCT personnel and from international experiences in this field. It should be noted that this is a single case study and that, although other cases may have similar challenges and benefits, these cannot be confirmed or denied in this research.

Section 8.1 Comment on the Adopted Methodological & Analytical Framework

A MMR framework grounded in pragmatism was adopted in this research – the results indicate the selected combination of methods and analytical tools were successful in answering the research questions. Data was collected through in-depth interviews with over 30 respondents (most from within the CCT), documentary evidence and direct and participant observation. By adopting various forms of triangulation in the data analysis, the validity and depth of the study was increased. The coherence of the data processed presented shows strong reliability of the results. Outlier responses are acknowledged and dealt with – none were discarded due to the exploratory nature of this research. A comprehensive model of the CCT PMS, the single case study, was required to understand the current system and highlight any apparent issues in achieving the land administration functions. A chain of evidence was established and a systems thinking approach was adopted in line with the LMP and applied to the CCT PMS, the system-in-focus, to model and analyse the current situation and the use and management of the PMO. Elements of SSM and BPM were pragmatically and successfully adopted for this process.

It is important to take into account international experiences, research and development in the realm of 3D cadastres and city models (Ghawana *et al.*, 2020). Therefore, the literature reviewed in Chapter 2 was used as a foundation for the analysis and discussion in Chapter 7. The conclusions drawn from the data collected generally agreed with the literature, adding validity to the choice of the methodological framework. Importantly, the analytical framework consisting of LAS theory including the LMP, SDI, RRRs and good governance principles (GGPs) were successfully used as a backdrop with which to compare the CCT PMS and make a more informed analysis of the current state of that system-in-focus and its ability to achieve sustainable development and the land administration goals as set out in the Land Management Paradigm.

Section 8.2 The Capabilities and Limitations of the Current CCT PMS with regards to Achieving the Land Administration Functions

The researcher acknowledges that the CCT PMS is faced with immense challenges, including financial, bureaucratic and human resource limitations, to name a few. In that context, it is can be said that the PMS manages the Property Management Object (PMO) and achieves the land administration functions as successfully as is possible within those harsh restrictions. However, this research does show that there are inherent and serious issues within the use, management and sharing of PMO data that could be addressed to the benefit of the CCT and urban management.

Therefore, the study concludes (Section 7.1) that the CCT PMS is limited with regards to the use, management and sharing of the PMO and the successful achievement of the land administration goals of land use, development and valuation, and is not fully functioning in line with the LMP or GGPs. The PMS has inherent data and systematic silos that prevent effective collaboration, integration and interoperability, effecting efficiency and effectivity of the land administration processes. The data quality is, in some cases, inadequate, including questionable metadata quality. Some datasets are duplicated while others are missing, and much of the value of datasets is not shared. It is possible to generalize that the issues of data integration, sharing and data quality may be city-wide and not be limited to only the PMS, based on the results of this research. Furthermore, the CCT PMS was selected as the single case study to represent SA local government PMS's. The results can be generalised[58] to all South African PMS's because local government legislation and processes are based on nationally defined legislation. Therefore, this research indicates that any SA PMS may have similar problems that need to be addressed within PMO use and management.

This research makes a major contribution to the current body of knowledge in the land administration domain in South Africa, by increasing the understanding of the South African Property Management System, in particular the CCT PMS. This appears to be the first attempt to create a model and analysis of the CCT PMS, with a focus on the PMO. Therefore, this is new knowledge that can be used in future for further research on the implementation of a 3D LAS.

Section 8.3 The Prospective Uses, Benefits and Potential Limitations of Introducing 3D into the CCT Property Management System

This study shows (Section 7.2) that the CCT has started to use 3D datasets for special projects on an ad-hoc basis. This illustrates the potential of 3D PMO records within the CCT and the potential challenges that may be faced. The research indicates that 3D can improve the LAS performance with regards to the land administration functions, because it:

- improving the comprehensiveness, accessibility, accuracy and reliability of the PMO,
- supporting data integration, collaboration and increased transparency,
- informing decision-making, evidence-based planning and policy development,
- offering in-depth and varied spatial analysis capabilities,
- promoting a better understanding of inherently 3D datasets,
- presenting a relatable and understandable perspective, increasing the accessibility of the data, improving public engagement
- supporting improved accuracy and fair valuations processes,
- and improving the efficiency and effectiveness of the land use, development and value processes.

It is shown that 3D models in a multipurpose cadastre can assist the CCT with achieving the GGPs and the SDGs, while facing the challenge of increasing complexity in the urban environment.

However, the challenges facing the CCT (see Section 7.1, Section 8.2) include the existing silos and lack of collaboration, as well as the dubious data quality of the core PMO datasets. The issues would need to be addressed before steps are taken to introduce a 3D record. Furthermore, designing and implementing a 3D solution will be expensive and resource-hungry, and the CCT currently has very limited financial, technical and human resources. It would require major change management and training that would be challenging. The

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[58] Using naturalistic generalisation (see 3.3.3i).

accessibility of a future 3D PMO is questionable; would it result in a technocratic system that excludes the majority of the population? Additionally, a full 3D technical solution does not exist anywhere in the world and the available software options are limited in terms of functionality. Future research into technical solutions will have to be rigorous and take into account the challenges mentioned here.

In conclusion, it is recognised that an effective RRRs record system has broad societal benefits and that increasing urbanisation is leading to a more complex and diverse environment that requires up-to-date, comprehensive and accessible records to improve land administration and achieve sustainable development (Indrajit *et al.*, 2020a,2018; Rajabifard & Ho, 2015). A 3D multipurpose cadastre in an integrated spatial data infrastructure supports the LAS and its four functions, as well as improving public participation, data integration, quality and accessibility, analysis capabilities, transparency and e-governance; this is in line with the GGPs (Enemark, 2006b; Williamson *et al.*, 2010; Jones & Land, 2012). Land administration and the PMO are inherently 3D and this study has shown that the potential benefits of introducing 3D into the CCT PMS could be significant. There are numerous challenges that would be faced, but the CCT PMS would benefit from adopting a 3D PMO record. Therefore, taking into account the conclusions drawn in Humby (2014), it is concluded that a third dimension is necessary within the SA LAS to improve land administration, to cope with urbanisation and to implement the SDGs at a City level.

Section 8.4 Recommendations for Further Research

The possible research avenues into 3D LAS are vast (Buyukdemircioglu & Kocaman, 2020). An in-depth analysis of the SA LAS should be conducted to begin design and implementation of a country-wide LADM that can act as the foundation from which to introduce 3D into the cadastre, the LTS and the Property Management System (PMS). Furthermore, a cost-benefit analysis is recommended to conclusively illustrate whether and where a 3D product is necessary and affordable (Griffith-Charles & Sutherland, 2013; Wong, 2015; Coote *et al.*, 2017; Vučić *et al.*, 2017; Hajji, 2018; Larsson *et al.*, 2020). The potential economic value of a 3D database should be calculated (Stoter *et al.*, 2016b) as well as the potential public value that may be added (Ho *et al.*, 2018). It should be conclusively determined if a 3D PMO record would add value to the current 2D GIS environment. Furthermore, rigorous research and analysis must be done into possible technical solutions for implementing a 3D record into the PMS, considering the challenges mentioned above that the CCT currently faces. The implementation of a 3D LAS case study within the CCT is recommended to aid that analysis and better illustrate the uses and benefits of 3D to stakeholders and potential users.

REFERENCES

"3DSM: 3D Smart Model for City of Cape Town". 2019. In *Property Value Chain March 2019 meeting*. Cape Town, South Africa: City of Cape Town.

van Ackere, S., Glas, H., Beullens, J., Deruyter, G., de Wulf, A. & de Maeyer, P. 2016. Development of a 3D Dynamic Flood Web GIS Visualisation Tool. In *Flood Risk Management and Response*. D. Proverbs & C.A. Brebbia, Eds. Southhampton, Boston: WIT Press. 106–115.

Aditya, T. & Laksono, D. 2017. LOD 1: 3D City Model for Implementing the Smart City Concept. In *The 2017 International Conference on Information Technology*. Singapore: 27-29 December 2017.

Aguilar-Savén, R.S. 2003. Business process modelling: Review and framework. *International Journal of Production Economics.* 90(2003):129–149.

Aien, A., Kalantari, M., Rajabifard, A., Williamson, I. & Wallace, J. 2013. Towards integration of 3D legal and physical objects in cadastral data models. *Land Use Policy*. 35(2013):140–154.

Alatalo, T., Koskela, T., Pouke, M., Alavesa, P. & Ojala, T. 2016. Virtual Oulu: Collaborative, Immersive and Extensible 3D City Model on the Web. In *Proceedings of the 21st International Conference on Web 3D Technology*. Anaheim, California: ACM Press. 95–103.

Aleksandrov, M., Zlatanova, S., Kimmel, L., Barton, J. & Gorte, B. 2019. Voxel-based Visibility Analysis for Safety Assessment of Urban Environments. In *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. V. IV-4/W8. 11–17.

Alford, J., Douglas, S., Geuijen, K. & T'Hart, P. 2017. Ventures in Public Value Management: Introduction to the Symposium. *Public Manag. Rev.* (19):589–604.

Atazadeh, B. 2017a. *Building Information Modelling for Urban Land Administration*. Melbourne, Australia: Doctoral thesis, The Department of Geomatics, The University of Melbourne.

Atazadeh, B., Kalantari, M., Rajabifard, A. & Champion, T. 2016b. Filling the space. *RICS Land Journal*. March/April 2016:24–25.

Atazadeh, B., Kalantari, M., Rajabifard, A., Ho, S. & Ngo, T. 2017b. Building Information Modelling for High-rise Land Administration. *Transactions in GIS*. 21(1):91–113.

Badenhorst, Pienaar & Mostert. 2006. *Silberberg and Schoeman's The Law of Property*. 5th ed. South Africa: LexisNexis.

Bakken, H.J. & Øverli, T.G. 2016. Improved land use planning in 3D. In *INSPIRE - Geospatial World Forum 2016*. Barcelona, Spain: 26 - 30 September 2016. Available: https://youtu.be/CuyNJEM8sLE [2020, August 08].

Barry, M. & Fourie, C. 2002. Analysing cadastral systems in uncertain situations: a conceptual framework based on soft systems theory. *International Journal of Geographical Information Science*. 16(1):23–40.

Barry, M. & Roux, L. 2012. A change based framework for theory building in land tenure information systems. *Survey Review*. 44(327):301–314.

Batty, M., Chapman, D., Evans, S., Haklay, M., Kueppers, S., Shiode, N., Torrens, P.M. & Smith, A. 2000. *Visualizing the city: communicating urban design to planners and decision-makers.* London, UK: Centre for Advanced Spatial Analysis, University College London.

Baxter, P. & Jack, S. 2008. Qualitative Case Study Methodology: Study Design and Implementation for Novice Researchers. *The Qualitative Report*. 13(4):544–559.

Bazan-Krzywoszańska, A., Mrówczyńska, M. & Tront, S. 2019. GIS Technology, 3D Models and Mathematical Models as a Tool for Assessing Development Capabilities of Flood Risk Land to Make Arrangements of Municipal Planning Documents. *Journal of Ecological Engineering*. 20(1):25–33.

Beer, S. 1995. *Diagnosing the System for the Organisation, the Managerial Cybernetics of Organisation*. Chichester, U.K.: John Wiley & Sons Inc.

Beil, C. & Kolbe, T.H. 2017. CityGML and the Streets of New York - a Proposal for Detailed Street Space Modelling. *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences*. IV-4/W5(2017):9–16.

Bell, S., Berg, T. & Morse, S. 2019. Towards an Understanding of Rich Picture Interpretation. *Systemic Practice and Action Research*. 32(6):601–614.

Benner, J., Geiger, A. & Häfele, K.H. 2016. Virtual 3D City Model Support for Energy Demand Simulations on City Level – The CityGML Energy Extension. In *21st International Conference on Urban Planning, Regional Development and Information Society*. Hamburg, Germany: 22-24 June 2016. 777–786.

Bennett, R., Wallace, J. & Williamson, I. 2005. Integrated Land Administration in Australia. In *Spatial Sciences Institute Biennial Conference*. Melbourne, Australia: September 2005.

Bennett, R., Rajabifard, A., Kalantari, M., Wallace, J. & Williamson, I. 2010. Cadastral Futures: Building a New Vision for the Nature and Role of Cadastres. In *FIG Congress 2010: Facing the Challenges – Building the Capacity*. Sydney, Australia: 11-16 April 2010.

Biljecki, F., Ledoux, H. & Stoter, J. 2017. Does a Finer Level of Detail of a 3D City Model Bring an Improvement for Estimating Shadows? In *Advances in 3D Geoinformation*. A. Abdul-Rahman, Ed. Delft, The Netherlands: Springer. 31–47.

Biljecki, F., Stoter, J., Ledoux, H., Zlatanova, S. & Çöltekin, A. 2015a. Applications of 3D City Models: State of the Art Review. *ISPRS International Journal of Geo-Information*. 2015(4):2842–2889.

Biljecki, F., Ledoux, H. & Stoter, J. 2016a. An improved LOD specification for 3D building models. *Computers, Environment and Urban Systems*. 59:25–37.

Biljecki, F., Arroyo Ohori, K., Ledoux, H., Peters, R. & Stoter, J. 2016b. Population Estimation Using a 3D City Model: A Multi-Scale Country-Wide Study in the Netherlands. *PLoS ONE*. 11(6):1–22.

Biljecki, F., Heuvelink, G.B.M., Ledoux, H. & Stoter, J. 2015b. Propagation of positional error in 3D GIS: estimation of the solar irradiation of building roofs. *International Journal of Geographical Information Science*. 29(12):2269–2294.

Biljecki, F., Ledoux, H., Du, X., Stoter, J., Soon, K.H. & Khoo, V.H.S. 2016c. The Most Common Geometric and Semantic Errors in CityGML Datasets. In *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. V. IV-2/W1. 13–22.

Billen, R., Cutting-Decelle, A.-F., Marina, O., de Almeida, J.-P., M., C., Falquet, G., Leduc, T., Métral, C., et al. 2014. *3D City Models and urban information: Current issues and perspectives: European COST Action TU0801*. Cedex, France: EDP Sciences.

Billen, R., Cutting-Decelle, A.-F., Metral, C., Falquet, G., Zlatanova, S. & Marina, O. 2015. Challenges of Semantic 3D City Models: A Contribution of the COST Research Action TU0801. *International Journal of 3-D Information Modeling*. 4(2):68–76.

Boeters, R., Arroyo Ohori, K., Biljecki, F. & Zlatanova, S. 2015. Automatically enhancing CityGML LOD2 models with a corresponding indoor geometry. *International Journal of Geographical Information Science*. 29(12):2248–2268.

Boyce, C. & Neale, P. 2006. Conducting Indepth Interviews: A Guide for Designing and Conducting Indepth Interviews for Evaluation Input. In *Pathfinder International Tool Series: Monitoring and Evaluation 2*. Watertown, MA: Pathfinder International.

Braun, R., Weiler, V., Zirak, M., Dobisch, L., Coors, V. & Eicker, U. 2018. Using 3D CityGML Models for Building Simulation Applications at District Level. In *IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC)*. Stuttgart, Germany: June 17-20, 2018: IEEE. 1–8.

Buhur, S., Ross, L., Büyüksalih, G. & Baz, I. 2009. 3D City Modelling for Planning Activities, Case Study: Haydarpasa Train Station, Haydarpasa Port and Surrounding Backside Zones, Istanbul. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. 38:1–4.

Burge, D.S. 2015. An Overview of the Soft Systems Methodology. In *System Thinking: Approaches and Methodologies*. Burge Hughes Walsh.

Buyukdemircioglu, M. & Kocaman, S. 2020. Reconstruction and Efficient Visualization of Heterogeneous 3D City Models. *Remote Sensing*. 12(2128):1–26.

Buyuksalih, G., Baskaraca, P., Bayburt, S., Buyuksalih, I. & Abdul Rahman, A. 2019. 3D City Modelling of Istanbul based on LiDAR Data and Panoramic Images - Issues and Challenges. In *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. V. XLII-4/W12. 51–60.

Bydłosz, J., Bieda, A. & Parzych, P. 2018. The Implementation of Spatial Planning Objects in a 3D Cadastral Model. *ISPRS International Journal of Geo-Information*. 7(153):1–14.

Çağdaş, V. & Stubkjær, E. 2011. Design research for cadastral systems. *Computers, Environment and Urban Systems*. 35(1):77–87.

Cappelle, C., El Najjar, M.E., Charpillet, F. & Pomorski, D. 2012. Virtual 3D City Model for Navigation in Urban Areas. *Journal of Intelligent & Robotic Systems*. 66(3):377–399.

Checkland, P. 1981. *Systems Thinking, Systems Practice*. Chichester, U.K.: John Wiley & Sons Inc.

Checkland, P. 1999. *Soft Systems Thinking, Systems Practice: Includes a 30-year Retrospective*. Chichester, U.K.: John Wiley & Sons Inc.

Choon, T.L. & Seng, L.K. 2014. Developing Infrastructure Framework to Facilitate the Malaysian Multipurpose 3D Cadastre. In *FIG Congress 2014: Engaging the Challenges, Enhancing the Relevance*. Kuala Lumpur, Malaysia: 16-21 June 2014.

Chundeli, F.A. 2017. Using 3D GIS as a Decision Support Tool in Urban Planning. In *The 10th International Conference on Theory and Practice of Electronic Governance*. New Delhi, India: 7-9 March 2017. 401–404.

City of Cape Town. 2011. CCT ISIS: The City of Cape Town's Integrated Spatial Information System: The Property Value Chain. Cape Town, South Africa: City of Cape Town.

City of Cape Town. n.d. *DAMS: What Is DAMS?* Available: http://www.capetown.gov.za/work and business/planning-portal/online-planning-and-building-resources/dams [2018, December 19].

Compion, J. 2015. Development Application Management System (DAMS): Planning & Building Development Management (PBDM). Cape Town, South Africa: City of Cape Town.

Constitution of the Republic of South Africa. 1996. Available: https://www.refworld.org/docid/3ae6b5de4.html [2021, August 15].

Coote, A., Knight, P., Colding, T.S., Home, R., Lysell, G., Streilein, J.F.A., Kane, P., Brady, K., et al. (in press). Assessing the Economic Value of 3D Geo-Information. *EuroSDR Official Publication*. 68:EuroSDR.

Corbett, J. & Mellouli, S. 2017. Winning the SDG battle in cities: How an integrated information ecosystem can contribute to the achievement of the 2030 sustainable development goals. *Information Systems Journal*. 27(4):427–461.

Coumans, F. 2019. 3D is the New Normal in Switzerland: Mapless Topographic Products Are the Future. *GIM International*. Available: https://www.gim-international.com/content/article/3d-is-the-new-normal-in-switzerland [2020, April 08].

Creswell, J.W. & Plano Clark, V.L. 2011. *Designing and conducting mixed methods research*. 2nd ed. Thousand Oaks, CA: Sage Publications Ltd.

Dembski, F., Wössner, U., Letzgus, M., Ruddat, M. & Yamu, C. 2020. Urban Digital Twins for Smart Cities and Citizens: The Case Study of Herrenberg, Germany. *Sustainability*. 12(2307):1–17.

Denscombe, M. 2008. Communities of Practice: A Research Paradigm for the Mixed Methods Approach. *Journal of Mixed Methods Research*. 2(3):270–283.

Denzin, N.K. 2012. Triangulation 2.0. *Journal of Mixed Methods Research*. 6(2):80–88.

Dewey, J. 2008. *The middle works of John Dewey, 1899-1924*. J. Boydston & L. Hahn, Eds. Carbondale: Southern Illinois University Press.

Dicicco-Bloom, B. & Crabtree, B.F. 2006. The qualitative research interview. *Medical Education*. 40:314–321.

Dimopoulou, E., Karki, S., Miodrag, R., Duarte De Almeida, J.-P., Griffith-Charles, C., Thompson, R., Ying, S. & van Oosterom, P. 2016. Initial Registration of 3D Parcels. In *5th International FIG 3D Cadastre Workshop*. Athens, Greece: 18-20 October 2016. 105–132.

Dimopoulou, E., Karki, S., Roić, M., Duarte de Almeida, J.P. & Griffith-Charles, C. 2018. 3D Cadastres Best Practices, Chapter 2: Initial Registration of 3D Parcels. In *FIG Congress 2018: Embracing our smart world where the continents connect: enhancing the geospatial maturity of societies*. Istanbul, Turkey: May 6–11, 2018.

DMS: City of Cape Town Development Management Scheme, Schedule 3 of the Municipal Planning By-Law. 2015.

DP: City of Cape Town Densification Policy. 2012.

Effenberg, W. 2001. *Spatial cadastral information systems: the maintenance of digital cadastral maps*. Melbourne, Australia: Doctoral thesis, The Department of Geomatics, The University of Melbourne.

Eisenhardt, K.M. 1989. Building Theories from Case Study Research. *Academy of Management Review*. 14(4):532–550.

Ellul, C. & Altenbuchner, J. 2014. Investigating approaches to improving rendering performance of 3D city models on mobile devices. *Geo-spatial Information Science*. 17(2):73–84.

Emamgholian, S., Taleai, M. & Shojaei, D. 2020. Exploring the applications of 3D proximity analysis in a 3D digital cadastre. *Geo-spatial Information Science*. 1–14.

Enemark, S. 2005. A Cadastral Tale. In *Week on Geomatics 2005*. Bogota, Columbia: 8-13 August 2005.

Enemark, S. 2006a. The Land Management Paradigm for Institutional Development. In *Sustainability and land administration systems: Proceedings of the expert group meeting on incorporating sustainable development objectives into ICT* *enabled land administration systems (pp.* I. Williamson, S. Enemark, & J. Wallace, Eds. University of Melbourne: Department of Geomatics. 17–29.

Enemark, S. 2006b. Understanding the land management paradigm: Need for establishing sustainable national concepts. *GIM International*. 20(1):12–15.

Enemark, S. 2006a. The Land Management Paradigm for Institutional Development. In *Sustainability and land administration systems: Proceedings of the expert group meeting on incorporating sustainable development objectives into ICT enabled land administration systems*. S. Enemark, I. Williamson, & J. Wallace, Eds. University of Melbourne: Department of Geomatics. 17–29.

Enemark, S., Williamson, I. & Wallace, J. 2005. Building modern land administration systems in developed economies. *Journal of Spatial Science*. 50(2):51–68.

Enemark, S., McLaren, R., Lemmen, C., Antonio, D. & Gitua, J. 2016. Scaling up responsible land governance: a guide for building fit-for-purpose land administration systems in less developed countries. In *2016 World Bank Conference on Land and Poverty*. Washington, D.C.: 14-18 March 2016. 1–37.

Fath, K., Stengel, J., Sprenger, W., Wilson, H.R., Schultmann, F. & Kuhn, T.E. 2015. A method for predicting the economic potential of (building-integrated) photovoltaics in urban areas based on hourly Radiance simulations. *Solar Energy*. 116:357–370.

Feilzer, M.Y. 2010. Doing Mixed Methods Research Pragmatically: Implications for the Rediscovery of Pragmatism as a Research Paradigm. *Journal of Mixed Methods Research*. 4(1):6–16.

FIG. 1995. FIG Statement on the Cadastre. In *FIG Publication No. 11*. Copenhagen, Denmark: The International Federation of Surveyors (FIG). Available: https://www.fig.net/resources/publications/figpub/pub11/figpub11.asp [2020, February 27].

Fisher, R. & Whittal, J. 2020. *Cadastre: Principles and Practice*. 1st ed. Cape Town, South Africa: South African Geomatics Institute (SAGI).

Fisher-Gewirtzman, D. 2018. Integrating 'weighted views' to quantitative 3D visibility analysis as a predictive tool for perception of space. *Environment and Planning B: Urban Analytics and City Science*. 45(2):345–366.

Ghawana, T., Sargent, J., Bennett, R.M., Zevenbergen, J., Khandelwal, P. & Rahman, S. 2020. 3D Cadastres in India: Examining the status and potential for land administration and management in Delhi. *Land Use Policy*. 98(2020):104389.

Godwin, A.N., Gore, M.B. & Salt, D.W. 1989. A Comparison of JSD and DFD as Descriptive Tools. *The Computer Journal*. 32(3):202–211.

Griffith-Charles, C. & Sutherland, M. 2013. Analysing the costs and benefits of 3D cadastres with reference to Trinidad and Tobago. *Computers, Environment and Urban Systems*. 40(2013):24–33.

Gröger, G., Kolbe, T.H., Nagel, C. & Häfele, K.H. Eds. 2012. *OGC City Geography Markup Language (CityGML) Encoding Standard*. Open Geospatial Consortium Inc.

Guney, C. 2016. Rethinking GIS Towards The Vision Of Smart Cities Through CityGML. In *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. V. XLII-2/W1. 121–129.

Guo, R., Li, L., Ying, S., Luo, P., He, B. & Jiang, R. 2013. Developing a 3D cadastre for the administration of urban land use: A case study of Shenzhen, China. *Computers, Environment and Urban Systems*. 40(2013):46–55.

Hajji, R. 2018. 3D Cadastre for Land Administration: Some issues about the Moroccan context. *African Journal of Geospatial Sciences and Land Governance*. ISSN2605-714X(1):85–93.

Hall, R. 2012. Mixed Methods: In Search of a Paradigm. In *International Conference: Innovative Research in a Changing and Challenging World*. S. Fan, T. Le, Q. Le, & Y. Yue, Eds. Tasmania, Australia: The Australian Multicultural Interaction Institute: 16-18 May 2012.

Herbert, G. & Chen, X. 2015. A Comparison of Usefulness of 2D and 3D Representations of Urban Planning. *Cartography and Geographical Information Science*. 42(1):22–32.

Herman, L. & Řezník, T. 2013. Web 3D Visualization of Noise Mapping for Extended INSPIRE Buildings Model. In *10th International Symposiumon Environmental Software Systems (ISESS)*. NeusiedlamSee, Austria: October 2013. 414–424.

Ho, S. & Rajabifard, A. 2016. Towards 3D-enabled urban land administration: Strategic lessons from the BIM initiative in Singapore. *Land Use Policy*. 57(2016):1–10.

Ho, S., Rajabifard, A., Stoter, J. & Kalantari, M. 2013. Legal barriers to 3D cadastre implementation: What is the issue? *Land Use Policy*. 35(2013):379–387.

Ho, S., Rajabifard, A. & Kalantari, M. 2015. "Invisible" constraints on 3D innovation in land administration: A case study on the city of Melbourne. *Land Use Policy*. 42(2015):412–425.

Ho, S., Crompvoets, J. & Stoter, J. 2018. 3D Geo-Information Innovation in Europe's Public Mapping Agencies: A Public Value Perspective. *Land*. 7(2):1–16.

Hofierka, J. & Zlocha, M. 2012. A New 3-D Solar Radiation Model for 3-D City Models. *Transactions in GIS*. 16(5):681–690.

Hull, S. & Whittal, J. 2013. Good e-Governance and Cadastral Innovation: In Pursuit of a Definition of e-Cadastral Systems. *South African Journal of Geomatics*. 2(4):342–357.

Humby, L. 2014. *3D Cadastral Parcels in South Africa: Representing the Third Dimension in the South African Cadastral System*. Cape Town, South Africa: Unpublished Honours Thesis: University of Cape Town. Available: https://www.researchgate.net/publication/329736098_3D_Cadastral_parcels_in_South_Africa_Representing_the_Third_Dimension_in_the_South_African_Cadastral_System [2020, February 27].

Humby, L. & Whittal, J. 2017. 3D Cadastral Parcels in South Africa – Representing the Third Dimension in the South African Cadastral System. In *FIG Working Week 2017: Surveying the world of tomorrow - from digitalisation to augmented reality*. Helsinki, Finland: 29 May – 2 June 2017.

IDP: City of Cape Town Integrated Development Plan 2017-2022. 2017.

IIP: City of Cape Town Investment Incentives Policy. 2018.

Indrajit, A., Ploeger, H., van Loenen, B. & Van Oosterom, P.J.M. 2018. Designing Open Spatial Information Infrastructure to Support 3D Urban Planning in Jakarta Smart City. In *Proceedings of the 6th International FIG 3D Cadastre Workshop*. P.J.M. Van Oosterom & D. Dubbeling, Eds. Delft, The Netherlands: International Federation of Surveyors (FIG). 329–356.

Indrajit, A., van Loenen, B., Ploeger, H. & van Oosterom, P. 2020a. Developing a spatial planning information package in ISO 19152 land administration domain model. *Land Use Policy*. 98(2020):104111.

Indrajit, A., Jaya, V.E., Loenen, B.V., Lemmen, C., Oosterom, P.V., Ploeger, H. & Theodore, R. 2020b. The Role of the Revised Land Administration Domain Model and Spatial Data Infrastructure in Improving Ease of doing

Busines in Indonesia. In *Institutions for Equity & Resilience, Annual World Bank Conference on Land and Poverty*. Washington, D.C.: 16 - 20 March 2020.

Isikdag, U., Horhammer, M., Zlatanova, S., Kathmann, R. & Van Oosterom, P.J.M. 2015. Utilizing 3D building and 3D cadastre geometries for better valuation of existing real estate. In *FIG Working Week 2015: From the wisdom of the ages to the challenges of modern world*. Sofia, Bulgaria: 17-21 May 2015.

"IUDF: Integrated Urban Development Framework: A New Deal for South African Cities and Towns". 2016. Pretoria, South Africa: Ministry of Cooperative Governance and Traditional Affairs.

Jackson, M.C. 2003. *Systems Thinking: Creative Holism for Managers*. Chichester, U.K.: John Wiley & Sons Inc.

Jakubiec, J.A. & Reinhart, C.F. 2013. A method for predicting city-wide electricity gains from photovoltaic panels based on LiDAR and GIS data combined with hourly Daysim simulations. *Solar Energy*. 93:127–143.

Janečka, K. & Karki, S. 2016. 3D Data Management: An Overview Report. In *The 5th International FIG 3D Cadastre Workshop*. Athens, Greece: 20-21 October 2016.

Johnson, R.B., Onwuegbuzie, A.J. & Turner, L.A. 2004. Mixed Methods Research: A Research Paradigm Whose Time Has Come. *Educational Researcher*. 33(7):14–26.

Johnson, R.B., Onwuegbuzie, A.J. & Turner, L.A. 2007. Toward a Definition of Mixed Methods Research. *Journal of Mixed Methods Research*. 1(2):112–133.

Jones, B. & Land, N. 2012. Cadastre 2.0 – A technology vision for the cadastre of the future. In *FIG Working Week 2012: Knowing to manage the territory, protect the environment, evaluate the cultural heritage*. Rome, Italy: 6-10 May 2012.

Jovanović, D., Milovanov, S., Ruskovski, I., Govedarica, M., Sladić, D., Radulović, A. & Pajić, V. 2020. Building Virtual 3D City Model for Smart Cities Applications: A Case Study on Campus Area of the University of Novi Sad. *ISPRS International Journal of Geo-Information*. 9(476):1–24.

Julin, A., Jaalama, K., Virtanen, J.-P., Pouke, M., Ylipulli, J., Vaaja, M., Hyyppä, J. & Hyyppä, H. 2018. Characterizing 3D City Modeling Projects: Towards a Harmonized Interoperable System. *ISPRS International Journal of Geo-Information*. 7(55):1–18.

Kaden, R. & Kolbe, T.H. 2014. Simulation-Based Total Energy Demand Estimation of Buildings using Semantic 3D City Models: *International Journal of 3-D Information Modeling*. 3(2):35–53.

Kalantari, M., Rajabifard, A., Wallace, J. & Williamson, I. 2008. Spatially referenced legal property objects. *Land Use Policy*. 25(2008):173–181.

Kalantari, M., Rajabifard, A. & Williamson, I. 2017. 3D Property Ownership Map Base for Smart Urban Land Administration. In *FIG Working Week 2017: Surveying the world of tomorrow - From digitalisation to augmented reality*. Helsinki, Finland: May 29–June 2, 2017.

Kalogianni, E., Dimopoulou, E., Quak, W., Germann, M., Jenni, L. & van Oosterom, P. 2017. INTERLIS Language for Modelling Legal 3D Spaces and Physical 3D Objects by Including Formalized Implementable Constraints and Meaningful Code Lists. *ISPRS International Journal of Geo-Information*. 6(319):1–36.

Karki, S. 2013. *3D cadastre implementation issues in Australia*. Melbourne, Australia: Doctoral dissertation: University of Southern Queensland.

Karki, S., McDougall, K. & Thompson, R. 2010. An overview of 3D Cadastre from a physical land parcel and a legal property object perspective. In *FIG Congress 2010: Facing the Challenges – Building the Capacity*. R. Staiger, Ed. Sydney, Australia: 11-16 April 2010.

Kaufmann, J. & Steudler, D. 1998. *Cadastre 2014 - A vision for a future cadastral system*. Switzerland: Rüdlingen and Bern.

Kemec, S., Duzgun, S., Zlatanova, S., Dilmen, D.I. & Yalciner, A.C. 2010. Selecting 3D Urban Visualisation Models for Disaster Management: Fethiye Tsunami Inundation Case. In *3rd International Conference on Cartography and GIS*. Nessebar, Bulgaria: 15-20 June 2010.

Kitsakis, D. & Dimopoulou, E. 2016. Possibilities of Integrating Public Law Restrictions to 3D Cadastres. In *5th International FIG 3D Cadastre Workshop*. Athens, Greece: 18-20 October 2016.

Kitsakis, D., Paasch, J.M., Paulsson, J., Navratril, G., Vučić, N., Karabin, M., El Mekawy, M., Koeva, M., et al. 2018. Legal foundations. In *Best Practices 3D Cadastres*. P. van Oosterom, Ed. Copenhagen, Denmark: International Federation of Surveyors (FIG). 1–66.

Koekemoer, P. 2017. Building Plans and other Submissions. Cape Town, South Africa: City of Cape Town.

Koekemoer, P. 2018. CCT Building Plan Application Process. Cape Town, South Africa: City of Cape Town.

Kolhatkar, S.S. 2011. XML Based Representation of DFD. *International Journal of Advanced Computer Science and Applications*. 2(8):22–24.

Krigsholm, P., Riekkinen, K. & Ståhle, P. 2018. The Changing Uses of Cadastral Information: A User-Driven Case Study. *Land*. 7(83):1–14.

Krüger, A. & Kolbe, T.H. 2012. Building Analysis for Urban Energy Planning using Key Indicators on Virtual 3D City Models: The Energy Atlas of Berlin. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. XXXIX-B2:145–150.

Kumar, K., Ledoux, H., Commandeur, T.J.F. & Stoter, J.E. 2017. Modelling Urban Noise in CityGML ADE: Case of the Netherlands. In *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences*. V. WG IV/1, WG IV/5 & WG IV/10. 73–81.

Kumar, K., Ledoux, H. & Stoter, J. 2018. Dynamic 3D Visualisation of Floods: Case of the Netherlands. *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. XLII-4/W10:83–87.

Kurakula, V. & Kuffer, M. 2008. 3D noise modeling for urban environmental planning and management. In *13th International Conference on Urban Planning in Information and Knowledge Society*. M. Schrenk, V. Popovich, D. Engelke, & P. Elisie, Eds. Vienna, Austria: May 19-21 2008: CORP, Competence Center of Urban and Regional Planning.

Kurwakumire, E. 2014. Digital Cadastres Facilitating Land Information Management. *South African Journal of Geomatics*. 3(1):64–77.

Labetski, A., van Gerwen, S., Tamminga, G., Ledoux, H. & Stoter, J. 2018. A Proposal for an Improved Transportation Model in CityGML. In *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. V. XLII-4-W10. 89–96.

Larsson, K., Paasch, J. & Paulsson, J. 2018. Conversion of 2D Analogue Cadastral Boundary Plans into 3D Digital Information – problems and challenges illustrated by a Swedish case. In *6th International FIG 3D Cadastre Workshop*. Delft, The Netherlands: 2-4 October 2018.

Larsson, K., Paasch, J.M. & Paulsson, J. 2020. Representation of 3D cadastral boundaries - From analogue to digital. *Land Use Policy*. 98(2020):104178.

Law, C., Lee, C., Lui, A.S., Yeung, M.K. & Lam, K. 2011. Advancement of three-dimensional noise mapping in Hong Kong. *Applied Acoustics*. 72(8):534–543.

Lenin Barath Kumar, D., Selvavinayagam, K. & Suresh Babu, S. 2014. Assessment of Crime & its Mapping Using Remote Sensing & 3D Geo-Spatial Model for Chennai City. *International Journal of Engineering Trends and Technology*. 3(3):418–425.

Leonard, A. & Beer, S. 1994. The Systems Perspective: Methods and Models for the Future. In *AC/UNU Millennium Project, Futures Research Methodology – Version 1.0*. J.C. Glenn, Ed. Washington: American Council for the United Nations University.

Leskens, J.G., Kehl, C., Tutenel, T., Kol, T., Haan, G. de, Stelling, G. & Eisemann, E. 2017. An interactive simulation and visualization tool for flood analysis usable for practitioners. *Mitigation and Adaptation Strategies for Global Change*. 22(2):307–324.

Li, D., Liu, G. & Liao, S. 2015. Solar potential in urban residential buildings. *Solar Energy*. 111(2015):225–235.

Li, L., Lei, Y., Tang, L., Yan, F., Luo, F. & Zhu, H. 2019. A 3D spatial data model of the solar rights associated with individual residential properties. *Computers, Environment and Urban Systems*. 74(2019):88–99.

Liang, J., Gong, J., Zhou, J., Ibrahim, A.N. & Li, M. 2015. An open-source 3D solar radiation model integrated with a 3D Geographic Information System. *Environmental Modelling & Software*. 64(2015):94–101.

Liang, J., Gong, J., Sun, J. & Liu, J. 2017. A customizable framework for computing sky view factor from large-scale 3D city models. *Energy and Buildings*. 149:38–44.

Lu, L., Becker, T. & Löwner, M.-O. 2017. 3D Complete Traffic Noise Analysis Based on CityGML. In *Advances in 3D Geoinformation*. A. Abdul-Rahman, Ed. Cham, Switzerland: Springer International Publishing. 265–283.

Lu, Z., Im, J. & Quackenbush, L. 2011. A Volumetric Approach to Population Estimation Using Lidar Remote Sensing. *Photogrammetric Engineering & Remote Sensing*. 77(11):1145–1156.

"LUM Process: Land Use Management Application Process Steps". n.d. Cape Town, South Africa: City of Cape Town.

Maree, K. & van der Westhuizen, C. 2007. Planning a Research Proposal. In *First Steps in Research*. K. Maree, Ed. Pretoria, South Africa: Van Schaik. 23–44.

McGaffin, R., Kirova, M., Viruly, F. & Michell, K. 2016. *Value Capture in South Africa - A Way to Overcome Urban Management Challenges and Unlock Development Opportunities?* UCT-Nedbank Urban Real Estate Research Unit.

Mele, C., Pels, J. & Polese, F. 2010. A Brief Review of Systems Theories and Their Managerial Applications. *Service Science*. 2(1–2):126–135.

Mendling, J., Reijers, H.A. & van der Aalst, W.M.P. 2010. Seven process modelling guidelines (7PMG). *Information and Software Technology*. 52(2):127–136.

Morgan, D.L. 2007. Paradigms Lost and Pragmatism Regained: Methodological Implications of Combining Qualitative and Quantitative Methods. *Journal of Mixed Methods Research*. 1(1):48–76.

Morgan, D.L. 2014. Pragmatism as a paradigm for social research. *Qualitative Inquiry*. 20(8):1045–1053.

Morris, A. 2015. *A Practical Introduction to In-depth Interviewing*. Thousand Oaks, CA: Sage Publications Ltd.

MPB: City of Cape Town Municipal Planning By-law. 2015.

"Annexure A: City of Cape Town Municipal Planning By-Law, 2019". 2019.

MPRA: Municipal Property Rates Act 6 of 2004. 2004.

MSDF: City of Cape Town Municipal Development Framework 2017 – 2022. 2017.

National Research Council (NRC). 1980. *Need for a Multipurpose Cadastre*. Washington, D.C.: National Academy Press.

Navratil, G. & Fogliaroni, P. 2014. Visibility Analysis in a 3D Cadastre. In *4th International Workshop on 3D Cadastres*. Dubai, United Arab Emirates: 9-11 November 2014.

NBR: National Building Regulations and Building Standards Act 103 of 1977. 1977.

Neuman, W.L. 2000. *Social Research Methods: Qualitative and Quantitative Approaches*. London, UK: Allyn and Bacon.

Neuville, R., Pouliot, J., Poux, F., de Rudder, L. & Billen, R. 2018. A Formalized 3D Geovisualization Illustrated to Selectivity Purpose of Virtual 3D City Model. *ISPRS International Journal of Geo-Information*. 7(194):1–24.

Neuville, R., Pouliot, J., Poux, F. & Billen, R. 2019. 3D Viewpoint Management and Navigation in Urban Planning: Application to the Exploratory Phase. *Remote Sensing*. 11(236):1–21.

Nielsen, A. 2005. Visual Representations, Usability and Urban Planning in Real-time 3D Geovisualization. In *8th AGILE Conference*. Estoril, Portugal: 26-28 May 2005.

Niewenhuis, J. 2007. Introducing Qualitative Research. In *First Steps in Research*. K. Maree, Ed. Pretoria, South Africa: Van Schaik. 46–66.

Nouvel, R., Schulte, C., Eicker, U., Pietruschka, D. & Coors, V. 2013. CityGML-based 3D city model for energy diagnostics and urban energy policy support. In *13th Conference of International Building Performance Simulation Association*. Chambéry, France: 26-28 August 2013.

Nouvel, R., Zirak, M., Dastageeri, H., Coors, V. & Eicker, U. 2014. Urban Energy Analysis based on 3D City Model for National Scale Applications. In *IBPSA Germany Conference*. Aachen, Germany: September 2014.

ODP: City of Cape Town Open Data Policy. 2014.

Ogle, F. 2017. Section 7 of the NBR Act and Relevant Case Law. Cape Town, South Africa: City of Cape Town.

O'Gorman, K. & Macintosh, R. 2015. Mapping Research Methods. In *Research Methods for Business & Management*. 2nd ed. K. O'Gorman & R. Macintosh, Eds. Oxford, UK: Goodfellow Publishers Ltd. 50–74.

Onsrud, H. 2003. Making a Cadastre law for 3D properties in Norway. *Computers, Environment and Urban Systems*. 27(4):375–382.

Onwuegbuzie, A.J. & Leech, N.L. 2006. Linking Research Questions to Mixed Methods Data Analysis Procedures. *The Qualitative Report*. 11(3):474–498.

van Oosterom, P. 2013. Research and development in 3D cadastres. *Computers, Environment and Urban Systems*. 40(2013):1–6.

van Oosterom, P., Stoter, J. & Ploeger, H. 2011. World-wide Inventory of the Status of 3D Cadastres in 2010 and Expectations for 2014. In *FIG Working Week 2011: Bridging the Gap between Cultures*. Marrakech, Morocco: 18-22 May 2011.

van Oosterom, P., Bennett, R., Koeva, M. & Lemmen, C. 2020. 3D Land Administration for 3D Land Uses. *Land Use Policy*. 98(2020):104665.

Paasch, J.M., Paulsson, J., Navratril, G., Vučić, N., Kitsakis, D., Karabin, M. & El Mekawy, M. 2016. Building a modern cadastre: legal issues in describing real property in 3D. *Geodetski vestnik*. 60(2):256–268.

Palmer, D., Fricska, S. & Wehrmann, B. 2009. *Towards Improved Land Governance*. United Nations: Food and Agriculture Organization (FAO) and United Nations Human Settlements Programme (UN-HABITAT).

Park, A.J., Spicer, V., Tsang, H.H., Behiels, K. & Song, J. 2019. Discovering Crime Trends and Patterns Using Three-Dimensional Visual Analytics. In *IEEE 10th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON)*. Vancouver, Canada: 17-19 Oct 2019.

Paulsson, J. & Paasch, J.M. 2013. 3D property research from a legal perspective. *Computers, Environment and Urban Systems*. 40(July 2013):7–13.

Peinhardt, K. 2015. *How cities can drive the Sustainable Development Goals*. Available: https://www.greenbiz.com/article/how-cities-can-drive-sustainable-development-goals [2020, September 13].

Pelto, J.P. & Pelto, G.H. 1978. *Anthropological Research: The Structure of Inquiry*. 2nd ed. New York, USA: Cambridge University Press.

Plano Clark, V.L. & Ivankova, N.V. 2016. *Mixed Methods Research: A Guide to the Field*. California, USA: Sage Publications Ltd.

Pouliot, J. & Girard, P. 2016. 3D Cadastre: With or Without Subsurface Utility Network? In *5th International FIG 3D Cadastre Workshop*. Athens, Greece: 18-20 October 2016.

Purkait, S. & Das, S. 2018. Smart Cities in India: Challenges Ahead. *The IUP Journal of Information Technology*. XIV(4):33–51.

Rabiee, M. & Rajabifard, A. 2017. Smart Sustainable Cities for All: A Socio-Spatial Approach. *Coordinates*. XIII(10):9–13.

Radulović, A., Sladić, D. & Govedarica, M. 2017. Towards 3D Cadastre in Serbia: Development of Serbian Cadastral Domain Model. *ISPRS International Journal of Geo-Information*. 6(312):1–21.

Rajabifard, A. & Ho, S. 2015. Towards smart future cities: 3D cadastres as a fundamental enabler. *Coordinates*. 11(4):8–11.

Rajabifard, A., Atazadeh, B. & Kalantari, M. 2019. *BIM and urban land administration*. Boca Raton, FL: CRC Press, Taylor & Francis Group.

Rajabifard, A., Atazadeh, B., Kalantari, M. & Williamson, I. 2018a. A New Method for Integrating 3D Spatial Information about Vertically Stratified Ownership Properties into the Property Map Base. In *FIG Congress 2018: Embracing our smart world where the continents connect: enhancing the geospatial maturity of societies*. Istanbul, Turkey: 6–11 May 2018.

Rajabifard, A., Agunbiade, M. & Kalantari, M. 2018b. An LADM-based Approach for Developing and Implementing a National 3D Cadastre – A Case Study of Malaysia. In *7th International FIG Workshop on the Land Administration Domain Model*. Zagreb, Croatia: 11-13 April 2018.

Rajabifard, A., Atazadeh, B. & Kalantari, M. 2018c. A critical evaluation of 3D spatial information models for managing legal arrangements of multi-owned developments in Victoria, Australia. *International Journal of Geographical Information Science*. 32(10):2098–2122.

Reicken, J. & Seifert, M. 2012. Challenges for the Multipurpose Cadastre. In *FIG Working Week: Knowing to Manage the Territory, Protect the Environment, Evaluate the Cultural Heritage*. Rome, Italy: 6-10 May 2012.

Reyes, M.E.P. & Chen, S.-C. 2017. A 3D Virtual Environment for Storm Surge Flooding Animation. In *IEEE Third International Conference on Multimedia Big Data (BigMM)*. Laguna Hills, CA: 19 April 2017.

Roić, M., Vranić, S., Kliment, T., Stančić, B. & Tomić, H. 2017. Development of Multipurpose Land Administration Warehouse. In *FIG Working Week 2017: Surveying the world of tomorrow - From digitalisation to augmented reality*. Helsinki, Finland: May 29 – June 2, 2017.

Romero Rodríguez, L., Duminil, E., Sánchez Ramos, J. & Eicker, U. 2017. Assessment of the photovoltaic potential at urban level based on 3D city models: A case study and new methodological approach. *Solar Energy*. 146(2017):264–275.

Roy, D.C. & Coors, V. 2011. 3D Web-based GIS for Flood Visualization and Emergency Response. In *73rd EAGE Conference and Exhibition incorporating SPE EUROPEC 2011*. V. May 2011. Vienna, Austria: European Association of Geoscientists & Engineers.

Sabri, S., Pettit, C.J., Kalantari, M., Rajabifard, A., White, M., Lade, O. & Ngo, T. 2015a. What are Essential requirements in Planning for Future Cities using Open Data Infrastructures and 3D Data Models? In *14th International Conference on Computers in Urban Planning and Urban Management*. Cambridge, MA, USA: 7–10 July 2015.

Sabri, S., Rajabifard, A., Ho, S., Namazi-Rad, M.-R. & Pettit, C. 2015b. Alternative Planning and Land Administration for Future Smart Cities. *IEEE Technology and Society Magazine*. 34(4):33–73.

Saeidi, S., Mirkarimi, S.H., Mohammadzadeh, M., Salmanmahiny, A. & Arrowsmith, C. 2019. Assessing the visual impacts of new urban features: coupling visibility analysis with 3D city modelling. *Geocarto International*. 34(12):1315–1331.

"SAP: Case study: How SAP runs Cape Town." 2013. Available: https://www.computerweekly.com/news/2240182802/Case-study-How-SAP-runs-Cape-Town [2018, December 19].

Saran, S., Wate, P., Srivastav, S.K. & Krishna Murthy, Y.V.N. 2015. CityGML at semantic level for urban energy conservation strategies. *Annals of GIS*. 21(1):27–41.

Saran, S., Oberai, K., Wate, P., Konde, A., Dutta, A., Kumar, K. & Senthil Kumar, A. 2018. Utilities of Virtual 3D City Models Based on CityGML: Various Use Cases. *Journal of the Indian Society of Remote Sensing*. 46(6):957–972.

SBP: City of Cape Town Sky Bridge Policy. 2012. V. C41/10/12.

Schrotter, G. & Hürzeler, C. 2020. The Digital Twin of the City of Zurich for Urban Planning. *PFG – Journal of Photogrammetry, Remote Sensing and Geoinformation Science*. 88(1):99–112.

Spatial Data Infrastructure Act 54 of 2003. 2003.

SDMF: City of Cape Town Spatial Data Management Framework. 2017.

SDMP: City of Cape Town Scenic Drive Management Plan. 2003.

Seale, C. 2004. *Researching Society and Culture*. 2nd ed. London, UK: Sage Publications Ltd.

Seifert, N., Mühlhaus, M. & Petzold, F. 2016. A Parametric 3D City Model: Basis for Decision Support in Inner-City Development. In *16th International Conference on Computing in Civil and Building Engineering*. 1285–1292.

Shepherd, I.D.H. 2008. Travails in the third dimension: a critical evaluation of three-dimensional geographical visualization. In *Geographic visualization: concepts, tools and applications.* M. Dodge, M. McDerby, & M. Turner, Eds. Chichester, U.K.: John Wiley & Sons. 199–222.

Shoshani, U., Benhamu, M., Goshen, E., Denekamp, S. & Bar, R. 2005. A Multi Layers 3D Cadastre in Israel: A Research and Development Project Recommendations. In *FIG Working Week 2005 and GSDI-8: From Pharaohs to Geoinformatics*. Cairo, Egypt: 16 - 21 April 2005.

Simpson, K.W. & Sweeney, G.M.J. 1973. *The Land Surveyor and the Law*. Durban, South Africa: University of Natal Press.

Skarbal, B., Peters-Anders, J., Faizan Malik, A. & Agugiaro, G. 2017. How to Pinpoint Energy-effecient Buildings? An Approach based on the 3D City Model of Vienna. In *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences*. V. IV-4/W3. 71–78.

van Son, R., Jaw, S.W., Yan, J., Khoo, V., Loo, R., Teo, S. & Schrotter, G. 2018. A Framework for Reliable Three-Dimensional Underground Utility Mapping for Urban Planning. In *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. V. XLII-4/W10. 209–214.

SPLUMA: South African Spatial Planning and Land Use Management Act 16 of 2013. 2013.

Steenekamp, S. n.d.(a). Informed Decisions: eGIS for a Smart City. Cape Town, South Africa: City of Cape Town.

Steenekamp, S. n.d.(b). eGIS: Lessons & Challenges on the Journey to "Maturity". Cape Town, South Africa: City of Cape Town.

Stoter, J. 2004. *3D Cadastre*. Delft, The Netherlands: Netherlands Geodetic Commission Publications on Geodesy.

Stoter, J., de Kluijver, H. & Kurakula, V. 2008. 3D noise mapping in urban areas. *International Journal of Geographical Information Science*. 22(8):907–924.

Stoter, J., Ohori, K.A., Dukai, B., Labetski, A., Kumar, K., Vitalis, S. & Ledoux, H. 2020. State of the Art in 3D City Modelling: Six Challenges Facing 3D Data as a Platform. *GIM International*. Available: https://www.gim-international.com/content/article/state-of-the-art-in-3d-city-modelling-2 [2020, August 23].

Stoter, J., Vallet, B., Lithen, T., Pla, M., Wozniak, P., Kellenberger, T., Streilein, A., Ilves, R., et al. 2016b. State-of-the-Art of 3D National Mapping in 2016. In *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. V. XLI-B4. 653–660.

Stoter, J., Ploeger, H., Roes, R., Ledoux, H., van der Riet, E. & Biljecki, F. 2016a. First 3D Cadastral Registration of Multi-Level Ownerships Rights in the Netherlands. In *5th International FIG 3D Cadastre Workshop*. Athens, Greece: 18-20 October 2016.

Tang, L., Ying, S., Li, L., Biljecki, F., Zhu, H., Zhu, Y., Yang, F. & Su, F. 2020. An application-driven LOD modeling paradigm for 3D building models. *ISPRS Journal of Photogrammetry and Remote Sensing*. 161(2020):194–207.

Tashakkori, A. & Teddlie, C. 2003. *Handbook of mixed methods in social and behavioural research*. Thousand Oaks, CA: Sage Publications Ltd.

TBP: City of Cape Town Tall Buildings Policy. 2013.

Tezel, D., Buyukdemircioglu, M. & Kocaman, S. 2019. Accurate assessment of protected area boundaries for land use planning using 3D GIS. *Geocarto International*. 1–14.

Threlfall, R. 2018. *Smart Infrastructure: Mapping Underground Utilities*. UK: KPMG LLP. Available: www.kpmg.com/uk/smartinfrastructure [2020, August 07].

Tjia, D. & Coetzee, S. 2013. Application of the land administration domain model to the City of Johannesburg land information system. *South African Journal of Geomatics*. 2(3).

Tomić, H., Roić, M. & Mastelić Ivić, S. 2012. Use of 3D cadastral data for real estate mass valuation in the urban areas. In *3rd International Workshop on 3D Cadastres: Developments and Practices*. ShenZhen, P.R. China: 25-26 October 2012.

UDP: City of Cape Town Urban Design Policy. 2013.

UN DESA. 2019. *World Urbanization Prospects: The 2018 Revision*. New York, USA: United Nations: Department of Economic and Social Affairs: Population Division. Available: https://population.un.org/wup/Publications/Files/WUP2018-Report.pdf [2021, February 21].

UN/ECE. 1996. *Land Administration Guidelines: With Special Reference to Countries in Transition*. Geneva, Switzerland.

United Nations. 2015. *Sustainable development knowledge platform*. Available: https://sdgs.un.org/goals [2020, September 13].

University of Cape Town. 2010. *Faculty of Engineering and Built Environment Code for Research Ethics.* Cape Town, South Africa: University of Cape Town. Available: http://www.ebe.uct.ac.za/ebe/research/ethics1 [2020, August 10].

Valstad, T. 2006. Development of 3D Cadastre in Norway. In *Shaping the Changes, XXIII FIG Congress*. Munich, Germany: 8-13 October 2006.

Van Oosterom, P.J.M., Thompson, R., Janečka, K., Zlatanova, S. & Kalantari, M. 2018. 3D Best Practices, Chapter 3: Cadastral Information Modelling. In *FIG Congress 2018: Embracing our smart world where the continents connect: enhancing the geospatial maturity of societies*. Istanbul, Turkey: May 6–11, 2018.

Vasilachis de Gialdino, I. 2009. Ontological and Epistemological Foundations of Qualitative Research. *Forum: Qualitative Social Research*. 10(2).

Verso, A., Martin, A., Amador, J. & Dominguez, J. 2015. GIS-based method to evaluate the photovoltaic potential in the urban environments: The particular case of Miraflores de la Sierra. *Solar Energy*. 117(2015):236–245.

Vučić, N., Roić, M., Mađer, M., Vranić, S. & van Oosterom, P. 2017. Overview of the Croatian Land Administration System and the Possibilities for Its Upgrade to 3D by Existing Data. *ISPRS International Journal of Geo-Information*. 6(223):1–20.

Wakker, W.J., van der Molen, P. & Lemmen, C. 2003. Land Registration and Cadastre in the Netherlands, and the Role of Cadastral Boundaries: The application of GPS technology in the survey of cadastral boundaries. *Journal of Geospatial Engineering*. 5(1):3–7.

Wallace, J. & Williamson, I. 2006. Developing Cadastres to Service Complex Property Markets. *Computers, Environment and Urban Systems*. 30(2006):614–626.

Wate, P., Rodrigues, P., Duminil, E. & Coors, V. 2016. Urban Energy Simulation based on 3D City Models: A Service-orientated Approach. In *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences*. V. IV-4/W1. 75–80.

Whittal, J. 2008. *Fiscal cadastral systems reform: a case study of the General Valuation Project 2000 in the City of Cape Town*. Doctoral thesis: University of Calgary.

Whittal, J. 2011. The Potential Use of Cellular Phone Technology in Maintaining an Up-to-date Register of Land Transactions for the Urban Poor. *Potchefstroom Electronic Law Journal*. 14(3):162–194.

Whittal, J. 2014. A New Conceptual Model for the Continuum of Land Rights. *South African Journal of Geomatics*. 3(1):13–32.

Whitten, J.L. & Bentley, L.D. 2007. *Systems Analysis and Design Methods*. 7th ed. New York, USA: McGraw-Hill Irwin.

Williamson, I., Enemark, S., Wallace, J. & Rajabifard, A. 2010. *Land Administration for Sustainable Development*. 1st ed. Redlands, California: ESRI Press Academic.

Wong, K.K.Y. 2015. *Economic Value of 3D Geographic Information*. London, UK: EuroSDR and the Department of Computer Science, University College London.

Yamamura, S., Fan, L. & Suzuki, Y. 2017. Assessment of Urban Energy Performance through Integration of BIM and GIS for Smart City Planning. *Procedia Engineering*. 180(2017):1462–1472.

Yamani, S.E., Ettarid, M. & Hajji, R. 2019. Building Information Modelling for an Enhanced Real Estate Valuation Approach based on the Hedonic Method. In *Building Information Modelling (BIM) in Design, Construction and Operations III*. V. 192. P. De Wilde, L. Mahdjoubi, & A. Garrigós Garrigos, Eds. (WIT Transactions on The Built Environment). Southhampton, England: WIT Press. 305–316.

Yamani, S.E., Billen, R. & Hajji, R. 2020. Towards a CityGML 3D Property Valuation Model based on BIM. In *GIST Seminar*. Delft, The Netherlands: 2 July 2020.

Yan, J., Jaw, S., Soon, K., Wieser, A. & Schrotter, G. 2019. Towards an Underground Utilities 3D Data Model for Land Administration. *Remote Sensing*. 11(1957):1–21.

Yin, R. 2003. *Case Study Research: Design and Methods*. 3rd ed. California: Sage Publications Ltd.

Ying, Y., Koeva, M., Kuffer, M. & Asiama, K. 2019. 3D Modelling for Property Valuation in China: A High-resolution Remote Sensing-based Approach. *GIM International*. Available: https://www.gim-international.com/content/article/3d-modelling-for-property-valuation-in-china-3 [2020, August 04].

Zevenbergen, J. 2002. *Systems of land registration: Aspects and effects.* (Publications on Geodesy no. 51). Delft, The Netherlands: Netherlands Geodetic Commission (NCG).

Zhang, H., Li, Y., Liu, B. & Liu, C. 2014. The Application of GIS 3D Modelling and Analysis Technology in Real Estate Mass Appraisal - Taking Landscape and Sunlight Factors as the Example. In *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. V. XL–4. 363–367.

Zhang, J., Yin, P., Li, G., Yu, Z., Hu, D. & Zang, Y. 2016. A New Method for 3D Cadastral Parcel Merging Based on Conformal Geometry Algebra. In *FIG Working Week 2016: Recovery from Disaster*. Christchurch, New Zealand: 2-6 May, 2016.

Zhao, W.J., Gao, S.P., Poh, H.J., Li, K.W. & Tan, T.T. 2016. Traffic Noise Prediction and Mapping with Virtual 3D City Models. In *InterNoise 16: INTER-NOISE and NOISE-CON Congress and Conference*. Hamburg, Germany: Institute of Noise Control Engineering. 576–581.

Zlatanova, S., van Oosterom, P. & Verbree, E. 2004. 3D technology for improving disaster management: Geo-DBMS and positioning. In *Proceedings of the XXth ISPRS Congress*. Istanbul, Turkey: 12–23 July 2004.

APPENDIX A: OPERATING DEFINITIONS

In the context of this research, these are the operating definitions:

Third dimension (3D)	The third dimension discussed in this research is not a true 'z', but is rather orthometric height, 'h'. Therefore, the property representations would not be truly 3D, but are rather "2D plus 1D representations of 3D space" (Humby & Whittal, 2017: 2). In the context of the PMO record, the height would be captured digitally in a geospatial format, and not as an attribute as it currently is (when that data is recorded at all). **However, this research is not attempting to propose a solution for the PMO record or introduction of 3D and therefore, the above definition and application may change.**
3D environment / 3D city model	A digital 3D city model that holds all information related to property. The 3D environment should include non-spatial attribute (semantic) data, for example, dates of import, services consumption data, number of persons living or working in a building, to maximize the benefits seen (Stoter *et al.*, 2020).
As-built	The current, existing buildings or built environment.
City GML	"City GML provides a standard model and mechanisms for describing 3D objects with respect to their geometry, topology, semantics and appearance; furthermore it defines five discrete levels of detail" (Herman & Řezník, 2013: 6)
PMO lifecycle	The definition, creation, management, use and destruction of land and property information.
Public value	Public value is the "value proposition is therefore about developing a strategy for an organization's activities that not only pursues traditional values around good governance, but more specifically focuses on matching tasks to specific issues which will enable the organization to better meet their public's expectations and desires" (Alford *et al.*, 2017 referenced in Ho *et al.*, 2018: 3).
Qualitative Research	Qualitative research seeks to understand a phenomenon within its context; the phenomenon and the context are seen as dependent (Niewenhuis, 2007: 48). It is typically associated with an interpretivism paradigm. Interpretivism employs the belief that the observer 'constructs' knowledge and reality through their own perceptions and experiences (Vasilachis de Gialdino, 2009).
Quantitative Research	Quantitative research is a systematic process that employs the objective use of numerical data from a select group within a population to draw conclusions that are generalizable to the larger population (Pieterson & Maree, 2007). It is typically grounded in positivist thinking (Henn *et al.*, 2009). Positivism is an approach defines all valid knowledge as factually-based on natural and observable phenomena, where logic and reason prevail (O'Gorman & Macintosh, 2015).
Smart City	There are multiple definitions of a smart city (Albino *et al.*, 2015) otherwise known as a digital twin (Kutzner *et al.*, 2020). Harrison *et al.* (2010: 2) provides a definition for a smart city as "connecting the physical infrastructure, the IT infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city". A smart city uses information and communications technologies to combine and analyse data from various sources (Albino *et al.*, 2015). By employing all the resources available, a smart city can allow for data flows between its subsystems, integrating and optimizing management to create a sustainable and habitable city (Ibid.). A revised version of CityGML (3.0) is due to be released that supports the requirements of smart city implementation and several cities around the globe have begun implementing smart city systems (Kutzner *et al.*, 2020). Importantly, a 3D city model, including a 3D multipurpose cadastre, is seen as an important tool to achieve

	a smart city (Atazadeh, 2017a; Billen *et al.*, 2015; Rajabifard & Ho, 2015; Aditya & Laksono, 2017; Jovanović *et al.*, 2020).
Solum	*Cuius est solum* defines ownership as the 3D pyramid-like shape extending from the centre of the Earth, through the parcel boundaries, into space and on to infinity (Badenhorst *et al.*, 2006; Mostert, 2012).
Spatial information / geospatial data	This research understands spatial information or geospatial data to be data that has a geospatial element and is spatially located. It may be vector, multipatch or raster data. "The main difference between geographic and other data is the spatiotemporal dimension of geographic data" (Herman & Řezník, 2013: 1).
Use case	As defined by Biljecki *et al.* (2015a: 2846), a use case is "a meaningful set of spatial operations that accomplish a goal a user wants to achieve with a spatial data set".

APPENDIX B: THE RESEARCH METHODOLOGY

The In-depth Interview Guide

An Example of the Interview Record:

Interview No.: I04 Date: ____________________

Participant Name: ______________________________ Time: ____________________

Organization: ______________________________ Place: ____________________

Interviewee Department: ______________________________ Participant Code: I04

Interviewee Job Title: ______________________________

Ethics Approval:

Audio record: Y / N

Participant gave permission to use his/her name: Y / N

Participant wishes to remain anonymous: Y / N

Participant wishes to remain anonymous, but with pseudonym: Y / N

Pseudonym: ________I04_______________

Participant gives permission to be quoted and identified: Y / N

Signed: __________________________

Date: ___________________________

3D CASE and PMS-PMO COMBINED Interview Schedule

General Introduction

Good day Mr./Ms. ....

I am Lara, it is lovely to meet you and put a face to your name/voice. As a brief introduction to my work – I am currently conducting research for my master's thesis in the Geomatics department at UCT. I am conducting research into **whether South Africa needs a 3D property record within the context of the current land administration system**. I wish to understand the CCT LAS, meaning all aspects of the CCT system that deal with land and property management.

The **purpose of this interview** is to understand your point of view, as an expert in your field, and gain a deeper understanding for the case at hand. Additionally, I want to pick your brain on 3D spatial information, or rather if you think there is a need for 3D in our current systems and if so, why.

Firstly, I would like **to clarify my understanding of the LAS** so that we are on the same page. The LAS consists of all agencies or parties that generate, edit, manage, make use of and archive property information of any kind. An agency can be anything from an organization, a department, a business or an individual. The LAS is the foundation that upholds land rights and the management of those rights. And this system in instructed by the Law.

The CCT is responsible for land administration like **land development, land use planning and valuation and taxation**. These form part of the greater LAS of SA.

I need to understand each agency within the CCT and how they use property data or contribute to land management. My aim is to create a visualization or map of the current CCT system related to land management and property.

Secondly, a **3D property record is an extension of the current records into the 3rd dimension**. This entails capturing property volumes or objects instead of land parcels or the 2D footprint of a 3D right.

General Guiding Interview Questions

1. What department do you fall under, what is your job title and what is your job role?
2. How would you describe this department's greater function? In other words, what is the purpose of the department you work for?
3. How does the department use or generate spatial data?
4. How do **you** interact with spatial data? I.e. generate, use, manage, destroy, etc. Can we list all the instances please?
5. If you or the department generates spatial data, how is it added to the greater LAS (e.g. is it a layer on a GIS?):
    - Who would use that data?
    - What is the circulation of this data within your department?
6. Do you have an organogram or department overview that I could make use of? Or could we draw one out together?
7. What other LAS departments does your department come into contact with and how?
8. Each department has their own GIS division – is that correct?
9. What is your opinion on that?
10. What is the flow of data between your department and the other departments? Let's draw a quick flow diagram.
11. Do you feel your department achieves its goals with respect to land administration and spatial data management?
12. What are the challenges that hold your department back?
13. Have you come across an instance in your role where you thought, this is a complex (maybe problematic) scenario and more spatial information (into the 3rd dim.) is needed?
    - Can we talk about that scenario please?
    - Is there any room that you can see, for misinterpretation or misunderstanding the situation?
        - Either by an expert with some form of spatial intelligence?
        - Or by a non-expert without spatial intelligence (i.e. struggles to read maps or plans)?

  - In this scenario, would more spatial data be helpful to you, specifically in your role?
  - And to anyone else?
  - Would a 3D record or visualization have aided you or anyone else wrt this case?
  - Could something have been done better or differently to avoid this issue?
14. Have you experienced a situation that has resulted in conflict, because of unclear record keeping? (Specifically with regards to the 3D).
    - Please can we discuss this?
15. Have you come across an instance where a 3D record has or may have been used to clarify a situation and aid the CCT in decision-making or management of property RRRs?
16. Do you feel "real-life" rights situations are adequately captured for (legal and administrative) record keeping and land management?
17. Do you think our current approach is sufficient for capturing and analysing cases like this one? (That are complex and 3D in nature.)
18. If not, let's discuss where you think our current system is failing.
19. Do you, in your professional opinion, see a purpose for a 3D record of property in the CCT land administration?
20. What do you foresee as the benefits a 3D record would introduce?
21. Can you see any potential pitfalls of introducing a 3D record into the CCT system?
22. Is there any other aspect of 3D cadastre that you have thought about and wish to mention now? E.G. Possible uses, possible downfalls, etc.

With regards to the 3D use case at hand:

1. Can we please record the details of the case:
    - Property details
    - Any other relevant contacts
    - Description of issue
    - Any image files available?
2. How were you involved in this case?
3. Did you find this case to be complex?
4. Did this complexity stem from the 3D nature of the case?
5. Did any particular part of this case strike you as problematic?
6. Could something have been done better or differently to avoid this issue?
7. Do you feel the real-life situation has been adequately captured for record-keeping?
8. Is there any room that you can see, for misinterpretation or misunderstanding the situation:
    - By an expert (who has spatial intelligence of some kind)?
    - Or by a non-expert (a person who does not have an understanding of spatial information, for example, cannot read a map or plans)?
9. Do you think our current approach is sufficient for capturing and analysing cases like this one? (That are complex and 3D in nature.)
10. If not, let's discuss where you think our current system is failing.

11. Do you, in your professional opinion, see a purpose for a 3D record of property in the CCT land administration?
12. What do you foresee as the benefits a 3D record would introduce?
13. Can you see any potential pitfalls of introducing a 3D record into the CCT system?

General Conclusion

Thank you very much for your time and effort.

I greatly appreciate it and will be sure to keep in touch with any developments if you are interested.

If need be, would you mind if I contact you again for a follow-up interview?

If you think of anything else that you would like to add, please contact me by email or on my phone.

APPENDIX C: FURTHER INFORMATION ON THE CCT PROPERTY MANAGEMENT SYSTEM (PMS)

The Property Value Chain Agents and a Summary of their Functions

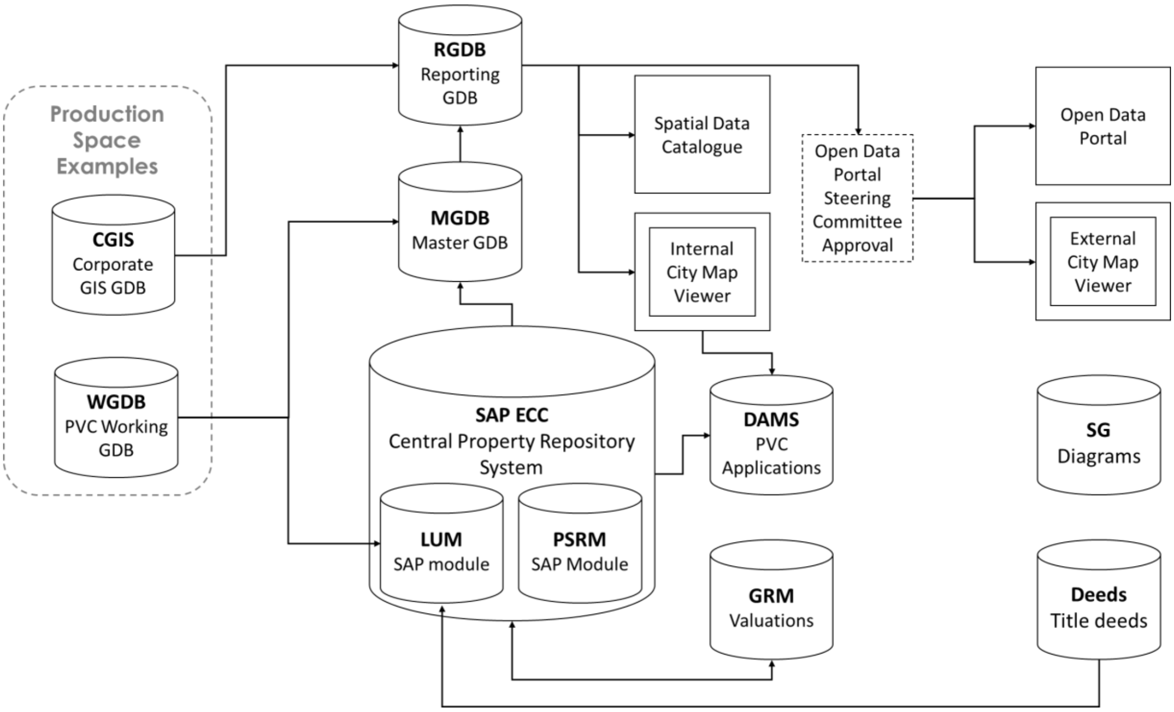
PROPERTY VALUE CHAIN AGENTS				
Planning & Building Development Management: Business Systems	**Planning & Building Development Management: Land Use Management**	**Planning & Building Development Management: Building Development Management**	**Finance: Valuations**	**Finance: Revenue**
Update property record: · Land parcels (SG diagram) · Property metadata (e.g. address, owner details) · Zoning (land use) · Sectional Title records · Servitudes	DMS* applications: · Rotate applications to relevant departments · Advertise · Reject / approve · Update property record with new zone / approved land use plan · Enforce DMS · Manage special + local overlay zones and urban development zones	Development applications: · Rotate applications to relevant departments · Reject / approve · Update property record with new approved plan · Inspections (comply with plans + NBR Act 103 / 1997) · Occupation certificates	Property valuations: · General valuation (once in 3 years) · Special valuations (change detected via LUM / BDM) · Data collection (Field / Remote) · Update property record (assign value, title deed records, land use and detailed property data, for example, type of view)	Property taxation: · Calculate rate (based on value) · Update rates account · Bill person (individual / business) · Update property record (financial record)

*Municipal Planning By-law,2015, Schedule 3: Development Management Scheme (DMS) (see 5.4.3.5.3.3ii).

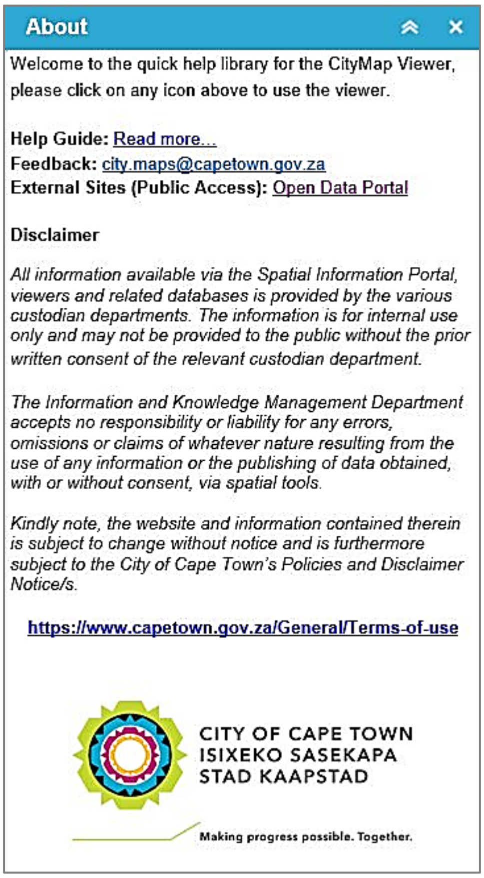
Other Relevant Departments that Use the Property Management Object (PMO)

Directorate	**Department**	**Function wrt PMO**
Transport	Network Management	Transport networks
	Asset Management & Maintenance	Use property information
	Transport Planning	Use property information
Water & Waste Services	Water & Sanitation Management	Utilities networks
	Solid Waste Management	Utilities networks
Energy & Climate Change	Electricity Generation & Distribution	Utilities networks
Human Settlements	Home Ownership Transfers, Tenancy Management & Staff Housing	Use property information
	Human Settlement Implementation	Use property information
	Informal Settlements & Backyarders	Use property information
	Integrated Urban Management	Use property information
Community Services & Health	City Health	Use property information
	Library & Information Services	Use property information
	Recreation & Parks	Use property information
	Social Development & Early Choldhood Development	Use property information
Safety & Security	Disaster Risk	Use property information
	Fire & Rescue Services	Use property information
	Law Enforcement	Use property information
	Traffic & Coordination	Use property information
Economic Opportunities & Asset Management	Facilities Management	Use property information
	Property Management	Use property information
Spatial Planning & Environment	Environmental Management	Use property information
	Urban Catalytic Investments	Use property information
Urban Management	Area Economic Development	Use property information
	Area Management	Use property information
	City Improvement Districts	Use property information

A more in-depth look at the GIS, Geodatabases and the CCT technical systems and how they interact



Internal City Map Viewer Disclaimer



Welcome to the quick help library for the CityMap Viewer, please click on any icon above to use the viewer.

Help Guide: Read more...
Feedback: city.maps@capetown.gov.za
External Sites (Public Access): Open Data Portal

Disclaimer

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Further Information on the Development Management Scheme (DMS)

The original definitions for ground levels as set out in the Municipal Planning By-Law (2015) have been redacted or replaced by Annexure A: Municipal Planning By-Law (2019) which was enacted in 2020. The original definitions are included here because they are pertinent to the Land Use Management (LUM) issues experienced by the CCT and highlighted in this thesis. The new definitions may or may not assist in solving these issues.

The original definitions are as follows:

Natural or existing ground level is defined as the ground surface level in its unmodified state, before any building has been erected or any alterations to the levels has been made. It can be established using an authorized contour plan, a registered surveyor's plan, or it can be determined by the CCT (*DMS*, 2015).

Average ground level is defined as the average of the highest and lowest existing ground levels that are taken at the points where the building or vertical divisions of that building intersect with the ground surface (*DMS*, 2015).

Base level is defined as the horizontal plane drawn at average ground level. The base level is used to determine the maximum development height for that erf according to its zoning rules (*DMS*, 2015).

Both 'average ground level' and 'base level' are removed and the 'existing ground level' definition is edited, as follows, in the annexure to the MPBL (2019):

Existing ground level "means the level of the land surface on a land unit as depicted on the City of Cape Town Ground Level Map. If this map has not been approved or is not applicable to a specific land unit(s), as determined by the City, then the following will apply to determine the level of the land surface on a land unit:

(a) in its unmodified state, before any building had been erected or alterations in levels had been made thereon; or

(b) [as] established from a plan indicating the contours of the land lodged with and accepted by an official agency such as the municipality or a government department, which depicts the existing level of the ground at or before the commencement date; or

(c) (c) in a state which has been graded, with the City's approval, for the purpose of development; or

(d) (d) as determined by the City, if in its opinion it is not possible to ascertain the existing level of the ground due to irregularities or disturbances of the land; and

the City may require the owner or applicant to commission a registered surveyor to measure levels of the ground or interpolate levels, which shall be tied to the National Control Network, or where this is not possible, to provide at least two durable reference marks suitably located, in order to provide the City with sufficient information so that it can determine the most appropriate existing ground level for the purpose of administrating this development management scheme"("MPBL", 2019: 9).

APPENDIX D: EXAMPLES OF INTEREST TO THE RESEARCH

The Blouberg Beach Road Case

The CCT policy requires high-density development along major public transport routes, for example, along Blouberg Beach Road that was designated a Primary Transport zone (see 5.1.4). It was identified that, although there had been huge infrastructure upgrades by the CCT to encourage development in this area, very little private development had been undertaken even though the development rights in the area were maximised. A subsequent analysis, that included a 3D visualization of the property RRRs, showed that there are blanket title deed restrictions across a large section of the Blouberg Beach Road erven that heavily limit development in the area. Unfortunately, the City had already invested in the area's infrastructure and removing the title deed restrictions is exceptionally difficult and costly. Therefore, it is shown that having a complete and accurate record of the Legal Property Object (LPO), including title deed restrictions and servitudes, and the vertical component of all RRRs, is exceptionally important for decision- and policy-makers within the CCT.

The Bo Kaap Monster Case

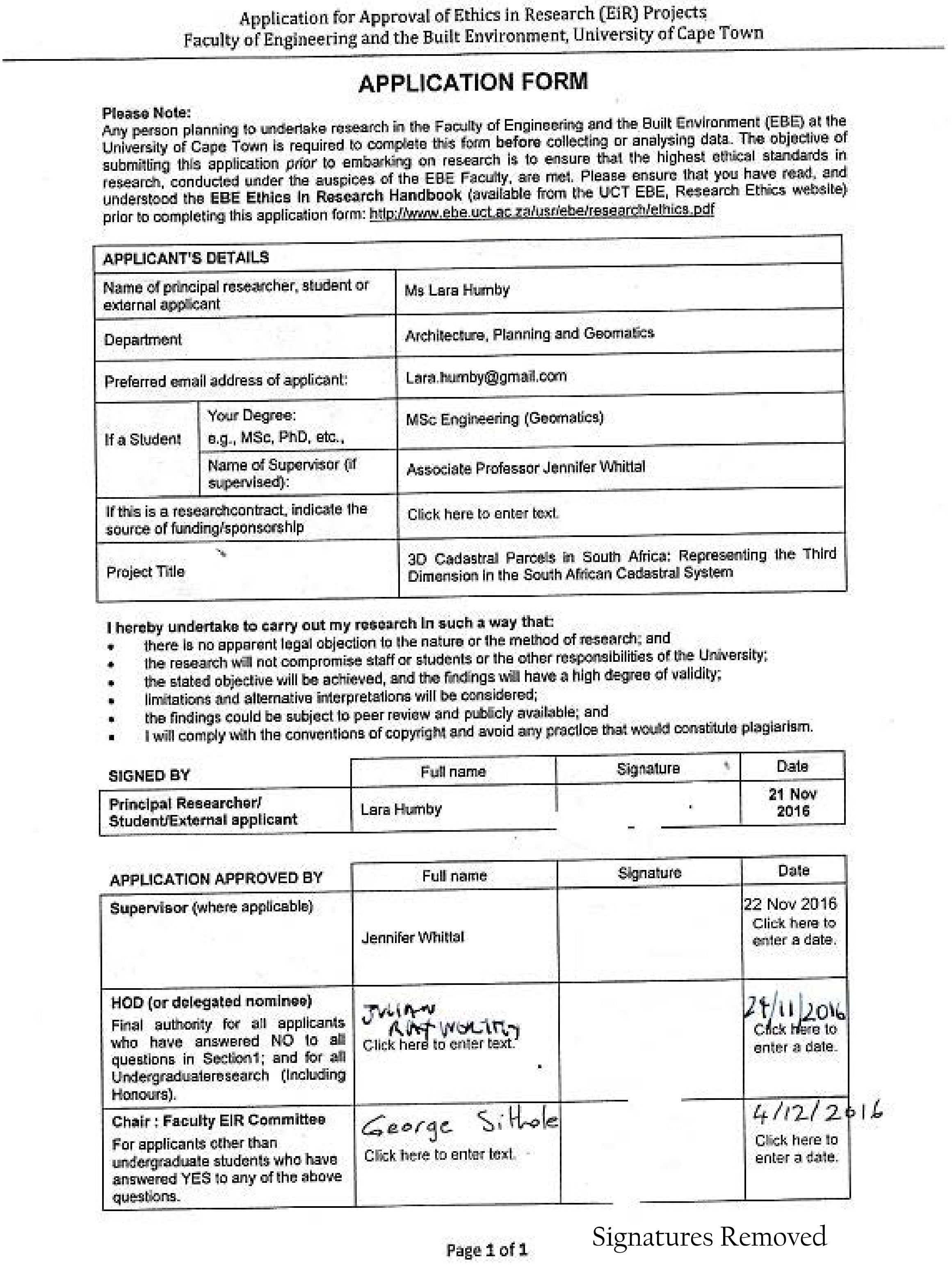
The Bo Kaap Monster case was extremely complex, controversial and caused massive public outcry (I04, I05). The sheer bulk of the proposed development and the effect that would have on the heritage overlay zone in the vicinity were the main cause for objection (I04). The case went through long court proceedings and was eventually approved (I03). This was an important case because it sets the legal precedent going forward (I04).

It was suspected that the developer manipulated a few of the 3D visuals to show off more positive viewpoints of the proposal in the application process (I04, I07). 3D models of the scenario were therefore produced by the CCT Geospatial unit and by an independent expert (I04, I05, I07). These showed the visual manipulation and clarified the case for the planners and the public (I04). A technical, more objective, analysis of the proposal imagery was conducted (I05).

Furthermore, the 3D models were found to be extremely useful in the litigation processes (I10, I28) and to illustrate the true effect of the proposal on the neighbourhood, and how it fits within the development envelope of that erf to check the compliance in a visual impact analysis (I04, I07, I10). It was felt by the planners that the 3D model allowed for a more objective assessment of the case (I10). A shadow analysis was conducted but it was not used in the court proceedings (I04).

APPENDIX E: RESEARCH APPROVAL DOCUMENTS

UCT Ethics Approval Form (approval dated 04/12/2018):



Application for Approval of Ethics in Research (EiR) Projects
Faculty of Engineering and the Built Environment, University of Cape Town

APPLICATION FORM

Please Note:
Any person planning to undertake research in the Faculty of Engineering and the Built Environment (EBE) at the University of Cape Town is required to complete this form **before** collecting or analysing data. The objective of submitting this application *prior* to embarking on research is to ensure that the highest ethical standards in research, conducted under the auspices of the EBE Faculty, are met. Please ensure that you have read, and understood the **EBE Ethics in Research Handbook** (available from the UCT EBE, Research Ethics website) prior to completing this application form: http://www.ebe.uct.ac.za/usr/ebe/research/ethics.pdf

APPLICANT'S DETAILS		
Name of principal researcher, student or external applicant		Ms Lara Humby
Department		Architecture, Planning and Geomatics
Preferred email address of applicant:		Lara.humby@gmail.com
If a Student	Your Degree: e.g., MSc, PhD, etc.,	MSc Engineering (Geomatics)
	Name of Supervisor (if supervised):	Associate Professor Jennifer Whittal
If this is a researchcontract, indicate the source of funding/sponsorship		Click here to enter text.
Project Title		3D Cadastral Parcels in South Africa: Representing the Third Dimension in the South African Cadastral System

I hereby undertake to carry out my research in such a way that:

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

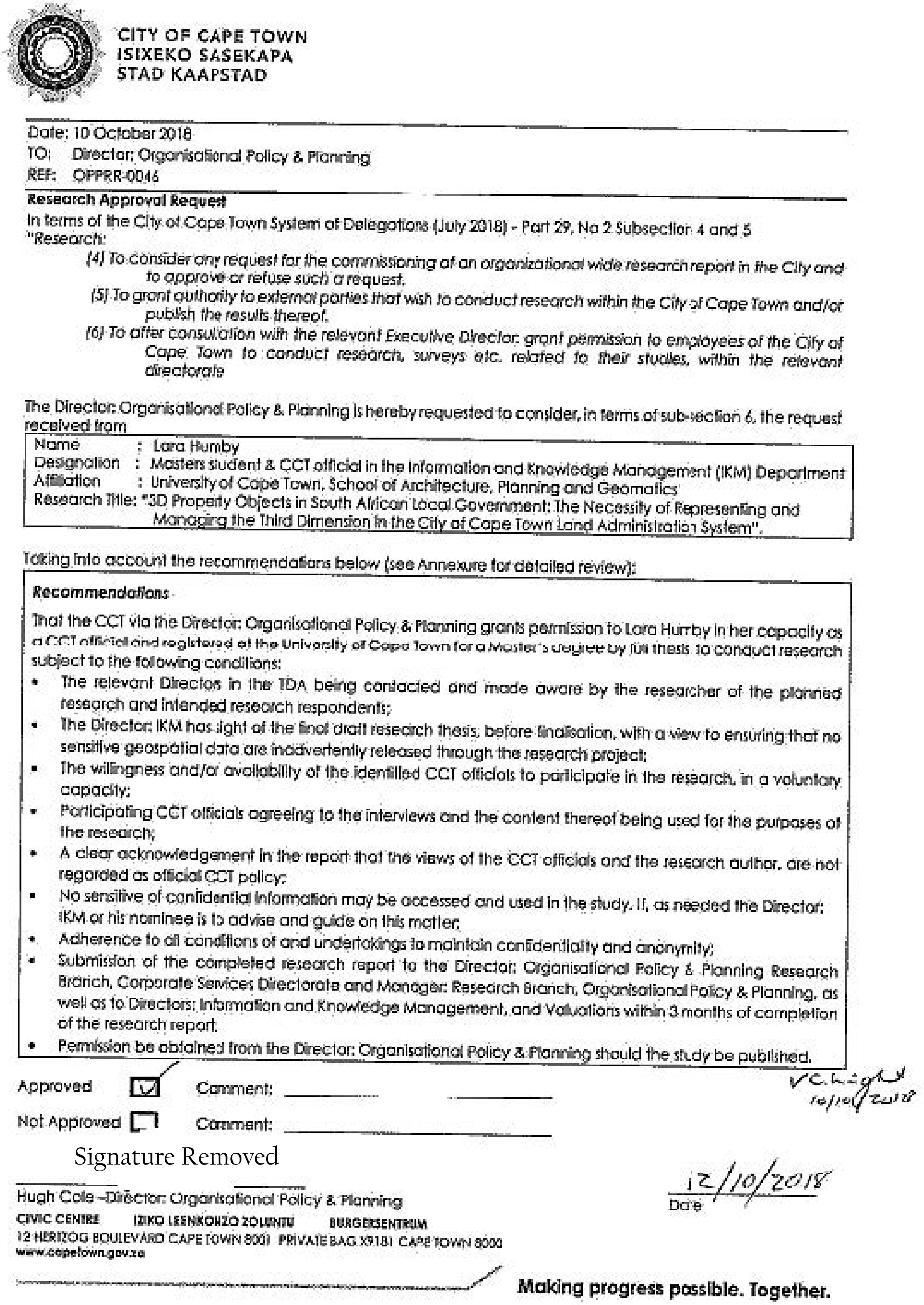
SIGNED BY	Full name	Signature	Date
Principal Researcher/ Student/External applicant	Lara Humby		21 Nov 2016

APPLICATION APPROVED BY	Full name	Signature	Date
Supervisor (where applicable)	Jennifer Whittal		22 Nov 2016 Click here to enter a date.
HOD (or delegated nominee) Final authority for all applicants who have answered NO to all questions in Section1; and for all Undergraduateresearch (Including Honours).	Julian [illegible] Click here to enter text.		29/11/2016 Click here to enter a date.
Chair : Faculty EIR Committee For applicants other than undergraduate students who have answered YES to any of the above questions.	George Sithole Click here to enter text.		4/12/2016 Click here to enter a date.

Page 1 of 1

Signatures Removed

CCT Research Approval (approval dated 12/10/2018):



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Date: 10 October 2018
TO: Director: Organisational Policy & Planning
REF: OPPRR-0046

Research Approval Request

In terms of the City of Cape Town System of Delegations (July 2018) - Part 29, No 2 Subsection 4 and 5 "Research:

(4) To consider any request for the commissioning of an organizational wide research report in the City and to approve or refuse such a request.

(5) To grant authority to external parties that wish to conduct research within the City of Cape Town and/or publish the results thereof.

(6) To after consultation with the relevant Executive Director grant permission to employees of the City of Cape Town to conduct research, surveys etc. related to their studies, within the relevant directorate

The Director: Organisational Policy & Planning is hereby requested to consider, in terms of sub-section 6, the request received from

Name : Lara Humby
Designation : Masters student & CCT official in the Information and Knowledge Management (IKM) Department
Affiliation : University of Cape Town, School of Architecture, Planning and Geomatics
Research Title: "3D Property Objects in South African Local Government: The Necessity of Representing and Managing the Third Dimension in the City of Cape Town Land Administration System".

Taking into account the recommendations below (see Annexure for detailed review):

Recommendations

That the CCT via the Director: Organisational Policy & Planning grants permission to Lara Humby in her capacity as a CCT official and registered at the University of Cape Town for a Master's degree by full thesis to conduct research subject to the following conditions:

- The relevant Directors in the TDA being contacted and made aware by the researcher of the planned research and intended research respondents;
- The Director: IKM has sight of the final draft research thesis, before finalisation, with a view to ensuring that no sensitive geospatial data are inadvertently released through the research project;
- The willingness and/or availability of the identified CCT officials to participate in the research, in a voluntary capacity;
- Participating CCT officials agreeing to the interviews and the content thereof being used for the purposes of the research;
- A clear acknowledgement in the report that the views of the CCT officials and the research author, are not regarded as official CCT policy;
- No sensitive of confidential information may be accessed and used in the study. If, as needed the Director: IKM or his nominee is to advise and guide on this matter;
- Adherence to all conditions of and undertakings to maintain confidentiality and anonymity;
- Submission of the completed research report to the Director: Organisational Policy & Planning Research Branch, Corporate Services Directorate and Manager: Research Branch, Organisational Policy & Planning, as well as to Directors: Information and Knowledge Management, and Valuations within 3 months of completion of the research report.
- Permission be obtained from the Director: Organisational Policy & Planning should the study be published.

Approved ☑ Comment: ____________ ____________

VC.Knight
10/10/2018

Not Approved ☐ Comment: ____________

Signature Removed

Hugh Cole – Director: Organisational Policy & Planning

12/10/2018
Date

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