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SUPERVISORS:
Dr. Rohan Bennett
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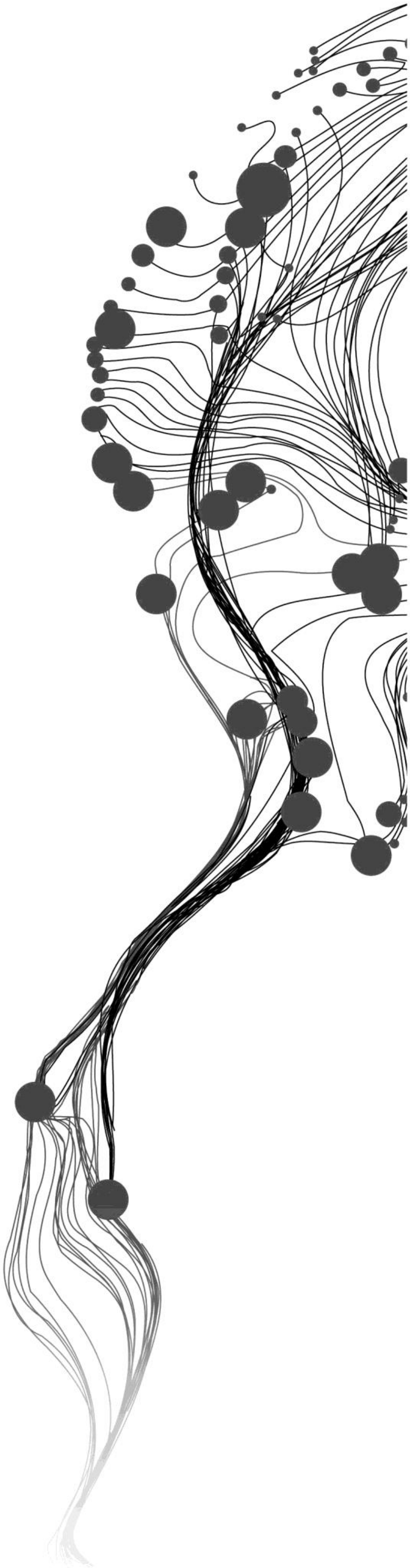

DESIGN AND ASSESSMENT OF A PROCEDURE FOR BUILDING AND MAINTAINING POINT CADASTRES

ROBERT HACKMAN ANTWI
Enschede, The Netherlands, February, 2012

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Land administration

SUPERVISORS:
Dr. Rohan Bennett
Ir. Walter de Vries

THESIS ASSESSMENT BOARD:
Prof. Ir. P. van der Molen (Chair)
Dr. F. Roy (External Examiner, Université Laval)
Dr. Rohan Bennett (First Supervisor)
Ir. Walter de Vries (Second Supervisor)

ABSTRACT

'Point cadastre' is a concept that applies single geographic points to represent parcels in a cadastral database. This innovative concept has been around for more than two decades and is sometimes referred to as 'Single Point Cadastre', 'Dots for Plots', 'lots by dots' or midpoint cadastre.

In this approach, boundary delineation and adjudication is of secondary concern and therefore the point cadastre can be completed much faster with little resources. The concept has potential in simple property taxation, basic tenure recordation, planning, and health management and so on, in both developed and developing countries. Current low cost spatial technologies including high resolution aerial imagery, handheld GPS receivers and open source GIS have created new opportunities for building and maintaining point cadastres. The objective of the research therefore is to design and assess a method of building and maintaining a point cadastre in line with relevant and pragmatic requirements and/or indicators.

Literature review and documentary analysis were undertaken to enhance the understanding of the point cadastre concept. Requirements for building and assessing point cadastre were established through discussions with some cadastral and mapping practitioners and also through questionnaire administered to some professionals from organisations including FIG, FAO, UNHABITAT and World Bank. These requirements then served as guidelines for the point cadastre design. Various components were designed to meet requirements that are directly related to building of point cadastres. The design was then tested and assessed in a prototyping environment. In each component designed, two or three option available to the researcher were applied and assessed.

In all twelve requirements relating to building components and assessment of points cadastres were established. Derived requirements relating to components for building a point cadastre are: application of available resources; coordinate reference system to apply; points for parcels representation (cadastral overlay); application of unique parcel identifier; and application of storage, display and query device. Requirements for the assessment ranked from most to least important using responses from the questionnaire are ease of use, cost, time/speed, flexibility, scalability and accuracy.

The major components employed in the design include the use of GIS software; GPS mapping device; and satellite images. The assessment results showed that application of Quantum GIS; Juno SD (field data collection tool) and onscreen digitisation; alphanumeric identifier; and Google images produce the best outcome based on the requirements.

The final design exhibits efficiency in terms of construction and maintenance; spatial accuracy; human capacity requirements; and system extension in a point cadastre for storing, displaying, querying and maintaining parcel data in the system. Further research could look into actual application of the design in a real situation especially in a developing country

Keywords: Point cadastres; single point cadastre; land administration

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List of Abbreviations

AMCHUD	African Ministerial Conference on Housing and Urban Development
CEP	Circular Error Probability
EGNOS	European Geostationary Navigation Overlay Service
FAO	Food and Agriculture Organization - United Nations
FIG	International Federation of Surveyors
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSM	Global System for Mobile Communications
ICT	Information Communication Technology
ISODATA	Iterative Self Organising Data Analysis Technique Algorithm
IT	Information Technology
LIS	Land Information System
PDOP	Position Dilution of Precision
QGIS	Quantum GIS software
RTK	Real Time Kinematics
SBAS	Satellite-Based Augmentation System
SDI	Spatial Data Infrastructure
SNR	Signal-to-Noise Ratio
STDM	Social Tenure Domain Model
UNECA	United Nations Economic Commission for Africa
UNHABITAT	United Nations Human Settlements Programme
WGS	World Geodetic System

1 INTRODUCTION

1.1 Introduction

According to (FIG, 2010) land information systems are facing challenges in the provision of the needed information in Land Administration for planning and development in several countries. Many factors including social, economic, technological and cultural are issues to consider in the development of LIS especially where coverage is low. Innovations and unconventional approaches in land administration are currently rising to confront these challenges regarding cadastral surveying in general. Among these approaches is the STDM which has enjoyed much attention lately. Another innovation is the Point cadastre. Current innovations in modern technology provides the perfect opportunity to revisit point cadastres to serve as a fast and cheap means of providing the needed land information for planning and development in general.

This research seeks to design and evaluate a modern procedure of building and maintaining a point cadastre as an alternative to the usual polygon representation of parcels and buildings in an LIS. The focus is on the cadastral data acquisition and mapping processes. This research results in the design of a modern method of building and maintaining point cadastres based on requirements and/or indicators tapped from literature and professionals in the cadastral field. Diverse modern surveying equipment and technologies employed in the test conducted had been subjected to assessment based on the requirements derived from both primary and secondary data sources. As such in this chapter, the research context and problem are introduced together with the objectives and questions. In addition to that the design matrix, sequence of activities and the thesis outline are also presented.

1.2 Background

Cadastral surveying and mapping is the foundation of the cadastral system. Generally, cadastral maps show land parcel boundaries. Due to historical, cultural and social differences, cadastral maps have varying contents and also play diverse roles in different jurisdictions including taxation, land use planning and other land administration (such as land allocation, land registration, property valuation, collection of land rent, etc) (Bełej, Źróbek, & Liang, 2002; Rajabifard, Williamson, Steudler, Binns, & King, 2007). Together with cadastral registers, cadastral maps support land tenure systems (Dale, 2000) and provides security that has become a basis for land markets (De Soto, 2000).

Cadastral databases consist of spatial and non-spatial components and may be acquired by various means. There are two basic approaches which may be adopted for cadastral surveying and mapping; one based solely on ground survey techniques and the other based on a combination of photogrammetric and ground survey techniques (Schermerhorn & Witt, 1953; Silayo, 2005)

Through the decades, several researchers including (C. Fourie, van der Molen, & Groot, 2002; Osterberg, 2001; Schermerhorn & Witt, 1953; Toulmin, 2009; UNECA, 1999) have the affordability of the cadastre. (AMCHUD, 2005) pointed out that the production cost of cadastral data is very high and the number of plots surveyed by land surveyors in a given period is also low.' In support of (AMCHUD, 2005), researchers including (Potsiou & Ioannidis, 2003; Williamson, 1994) argue that the regulatory framework, technical standards, and methods as well as the administrative procedures that go with operations of cadastral surveys are the causes of the high costs and delays. In spite of the numerous attempts in reforming cadastral systems, the anticipated benefits however are seldom attained in practice (Barnes, Moyer, & Gjata; Grenville, 2003; Griffith-Charles, 2002).

According to (FIG, 1995), cadastres are successful when they are clear, simple and easily accessible to both maintainers and users of cadastral data. In addition, they should provide tenure security to landholders; and must provide current and reliable information to land stakeholders at the lowest possible cost. To attain this, cadastral and mapping practitioners have introduced several technologies. For example in Indonesia and elsewhere, land agency staff (or simply BPN) conducted trials in the use of handheld GPS for cadastral surveys in 1995. At this time, these trials proved very promising in terms of cost reductions, more rapid surveys, accuracy, and improved flexibility (Holstein, 1996). Furthermore, (Home & Jackson, 1997) explain that American Planning Consultants, Padco Inc used a point-based approach in Thailand, Philippines, Indonesia and Honduras which recorded enormous successes. They observed that a point-based cadastre could potentially provide faster solutions in areas where land information is almost non-existent for decision making than conventional cadastres. However they limited the utilisation of point-based cadastre to representing the spatial units (like parcels, apartments and buildings only). Recently, the trial with point-based cadastre attracted attention from researchers in light of the design generic database model for cadastres (Lemmen, 2010; Lemmen & van Oosterom, 2006; P. van Oosterom et al., 2006). As a result the point-based cadastre concept forms part of the new pro poor tool, Social Tenure Domain Model (STDM)(Lemmen, Augustinus, Oosterom, & Molen, 2007) and The Core Cadastre Domain Model (P. van Oosterom, et al., 2006).

In the same vein (Griffith-Charles, 2011) mention that the point principle can be partially applied to fill in gaps in the boundary survey of parcels. He suggested that aerial photograph, satellite image, or handheld GPS can be used in addition and the actual parcel extents described textually. This he claims can later be converted into boundaries usually found in cadastres.

Even though the point cadastre concept is not very new, very little has been done in terms of research to establish its real potential in the contemporary context of tools and technology for mapping. Point cadastres could provide solutions in areas where cadastres are completely destroyed or are unavailable and require very fast and cheap means to build one.

1.3 Research Problem

Although modern survey equipment and technologies have provided cheaper and more reliable techniques of land description and identification, researchers and organisations including (C. Fourie, et al., 2002; UN HABITAT, 1990) have observed that cadastral survey processes are still expensive and have suggested that simplified cadastral survey methods and procedures should be adopted. Point cadastres are one options being touted as a possible solution. However, exactly how to apply this method especially in this present time is still missing and therefore require some attention.

Padco Incorporation claims that point cadastre have potential for serving as a replacement to the usual method of building cadastres which are known to be characterised by high cost and very slow. Though several authors share this view, the absence of a sequential procedure to construct a point cadastre could be part of the reason why it still lacks patronage. Current technologies available today have contributed in current surveying problems but their potential in point cadastre surveying has neither been fully tested nor evaluated. Moreover, there is no doubt about the potential application of handheld GPS technology but by integrating with GIS and satellite imagery (Google) in cadastral surveying and mapping has seen little study.

In this context three issues can be brought to the attention of researchers; 1) To design a procedure for building and maintaining a point cadastre, 2) to develop and execute a test of a point cadastre using modern tools, and 3) to evaluate the method for building a point cadastre based on generally accepted requirements.
In summary, the study addresses the issue of design and assessment of a method of building and maintaining point cadastres. For the realization of this, field data collection based on specified methods put together from various sources has been undertaken. The method involves collecting data from study area using hand held and high-grade GPS receivers, and also satellite images as base layers.

Finally, this design research aims at contributing developing effective methods of building and maintaining a quick fiscal cadastre that serves as a good starting point for the renewal or establishment of a cadastral system where it is urgently required (Zevenbergen & Bogaerts, 2001).

1.4 Research Objectives

1.4.1 Overall Objective

The main objective of this research is to design and assess a modern method of building and maintaining a point cadastre in line with relevant/pragmatic requirements and/or indicators. This involves assessing various options in terms of components and processes in a prototype for building and maintaining the system.

1.4.2 Sub-Objectives

The sub-objectives are:

1. To understand the concept of point cadastre
2. To design a method for building and maintaining a point cadastre
3. To validate the new design method for building a point cadastre based on relevant/pragmatic requirements and/or indicators derived in this research

1.5 Research Questions

In line with the research problem and objectives, four research questions outlined below were derived. These questions directly address the sub-objectives which eventually cater for the main objective.

- 1.0) What is a point cadastre
  - 1.1) Which examples of point cadastres exist?
  - 1.2) Which characteristics do these examples exhibit?
  - 1.3) How can different types of point cadastres be classified?
  - 1.4) What are the existing approaches to developing point cadastre?
  - 1.5) What are the pros and cons of point cadastre?
- 2.0) What are relevant and pragmatic design requirements for building a point cadastre and what are relevant and pragmatic requirements (indicators) to assess a point cadastre?
- 3.0) How can one design a modern method for building and maintaining a point cadastre based on the indicators/ requirements derived in this research?
- 4.0) How can the method designed be validated in terms of the indicators/ requirements?

1.6 Research Methods

This research adopts the "waterfall" approach in designs to achieve the objectives. In this approach a steady downward progress through background review, requirements, design and prototyping are applied. First, literature search was undertaken to obtain a good insight of the concept. Interactions with land administration professionals also provided further understanding of the concept as well as helping to establish the needed requirements for building and maintaining point cadastres. Additional data collected from other land administration experts through questionnaires was used for testing the reliability of the requirements.

To relate the research objectives and questions, the following data collection and analysis methods were used:
Literature (reports) review: This analysis was undertaken in order to acquire relevant data from the existing literature on point cadastre map compilation and applications in order to obtain in-depth knowledge about the existing practices. Conventional methods of building a cadastre in general were also analysed. Analysis of the results were be done while focusing on the objectives of the research.

Discussions: discussions were conducted with survey and Land administration professionals to obtain primary data on their views on point cadastre as. This provided the researcher the opportunity to have a better insight of point cadastres and how the professionals actually envisage the practicability of the concept. Some requirements for building point cadastre emerged from the two separate discussions involving seven professionals in total, five of whom are staff of Kadaster International.
Questionnaire: primary data sort by means of questionnaires were undertaken for the validating the point cadastre requirements. The target group were some land administration experts from recognised international organisations. The derived requirements served as the basis in the initial design of the point cadastre.

Field experiment: With the assessment framework options available for the final design are assessed in a prototyping environment. This was done by the assessment of processes for developing point cadastre in the sample area. Within this process, acquisition of base images, building of the database and spatial data collection were undertaken. All the processes were carried out along with the assessment based on the requirements obtained. Available options in base layers, data collection equipment and GIS software applied were assessed among others. Further field experimenting, downloading, processing and comparison with existing datasets were undertaken as part of the validation procedures. These resulted in both qualitative and quantitative outcome. According to (Sechrest & Sidani, 1995), employing both methods provides opportunity for quantitative analysis to check out qualitative observation whereas quantitative observation is verified by qualitative analysis.

Specific parts of all phases are discussed in detailed together with the results in the various chapters. The sample area is the neighbourhood of Enschede, Netherlands.

1.7 Research Design Matrix

The research design matrix is a planning tool that acts as a prompt in the data collection part of the study as it highlights the concepts that have to be defined and the variables that have to be estimated. It forces the researcher to determine the techniques to be used at the very beginning of the research exercise (Choguill, 2005).

In this design matrix (Table 1-1), the research sub-objectives, sub-questions and the approaches adopted in acquiring the data are outlined. Obtaining answers to the questions required diverse secondary data sources.

This includes: i) journal articles including both ISI and non-ISI journals, ii) conference papers iii) book chapters iv) textbooks, v) web access to printed sources and vi) web pages.

Sub-objectives	Research sub-questions	Research Approach	Source of evidence data collected
To understand the concept of point cadastre	1.1) Which examples of point cadastres exist?	Literature review Archival review, Discussions with practitioners,	Available articles in web of science, Grey literature from cadastral domain, OICRF database, ITC library catalogue, Science direct Discussions with Kadaster International
	1.2) Which characteristics do these examples exhibit?	Literature review Archival review,	All collected documentary
	1.3) How can different types of point cadastres be classified?	Coding and qualitative analysis	None
	1.4) What are the existing approaches to developing point cadastre?	literature analysis; qualitative coding of documents	All found and selected documents (scientific and grey literature)
	1.5) Which pros and cons of point cadastres do practitioners describe?	literature analysis; qualitative coding of documents	All found and selected documents (scientific and grey literature)
	2.0) What are relevant and pragmatic design requirements for building a point cadastre and what are relevant and pragmatic requirements (indicators) to assess a point cadastre?	Qualitative review Qualitative coding and review of discussions Qualitative and qualitative analysis survey results	Literature Review, Documentary Analysis Discussions with Kadaster International Questionnaires to practitioners
To design method for building point cadastre	3.0) How can one design a modern method for building a point cadastre based on these indicators/ requirements?	Design Research - prototyping	Requirements (components) generated in requirement phase
To validate the method for building a point cadastre in terms of derived requirements.	4.0) How can the method design be validated in terms of derived requirements?	Assessment of the Prototyping process	Field measurements Prototyping procedures

Table 1-1: Design Matrix

1.8 Sequence of Activities

The entire research follows a strict sequence of activities in order to keep on track and to stay within limits. In order to complete the entire research the following activities were adopted in this sequence: 1) Research Aim and Problem; 2) Compilation of validated requirements; 3) Framework Designs; 4) Test and Assessment of Procedure; and 5) Conclusion/recommendation. The manner in which this was carried out sequentially is summarized in **Error! Reference source not found.** below.

An initial scan across available books and articles provided a first insight in the research problem and helped to derive a main research objective and sub-objectives. The research questions were gradually formulated based on the initial findings and experiments. Addressing these eventually led to the completion of the research.

This research made use of both quantitative and qualitative methods in the compilation of validated requirements. In this regard, discussions with land administration and surveying professionals were conducted to collect their experiences and ideas on point cadastre concept and cases. Existing literature as well as documentary evidence on point cadastre was also part of the initial analysis on concepts. Creating qualitative literature review derived a comprehensive understanding of both point cadastre concepts and practical applicability. This understanding translated into design requirements which could be validated through a survey to land administration professionals.

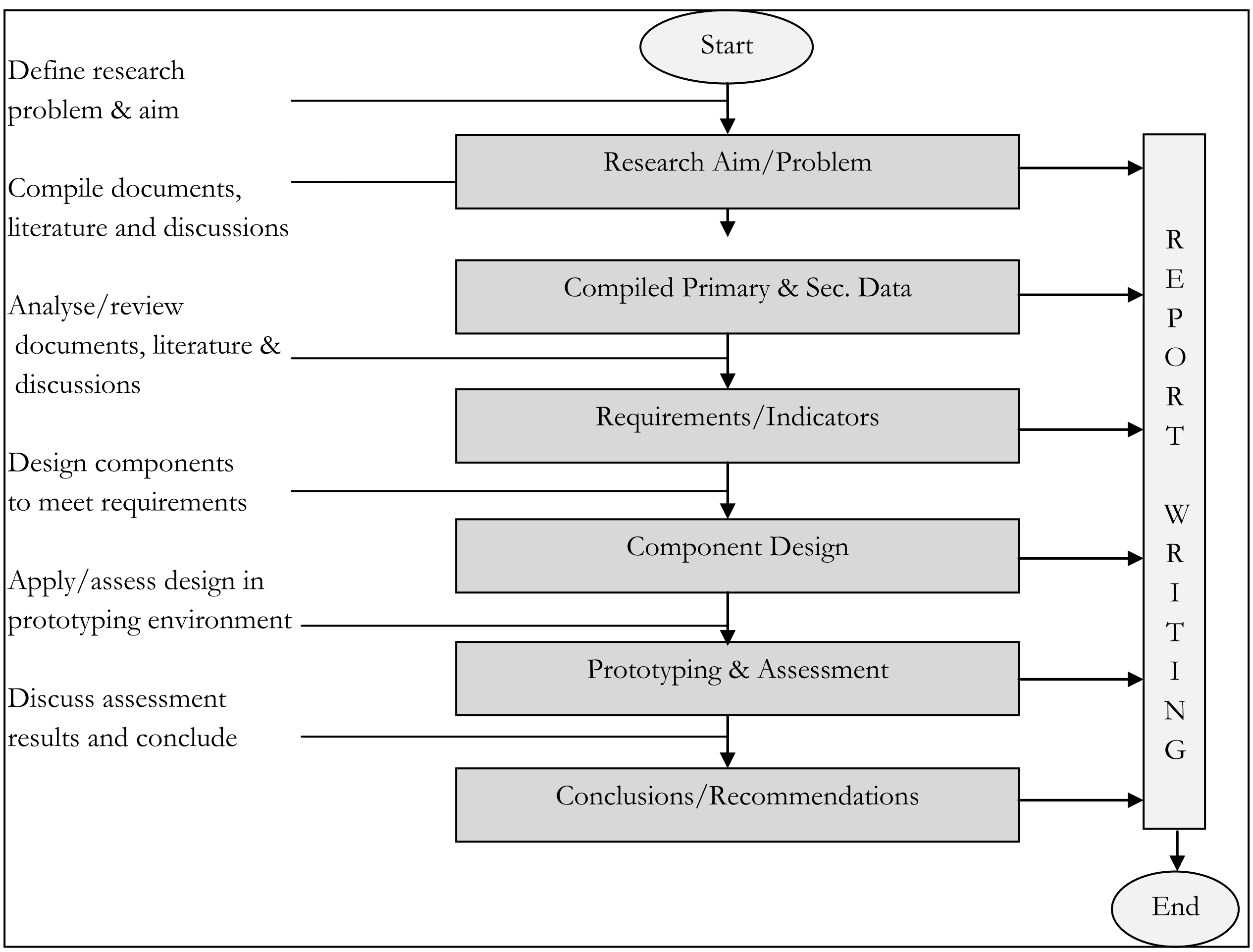

Figure 1-1: Sequence of Activities

Based on a broader understanding of point cadastre concepts the design and assessment procedure were prepared. With reference to the validated requirements components were initially designed to meet them. Options available in each component were assessed using an assessment framework designed earlier. The framework is a matrix based on the requirements and components used in the design.

Basically, deduction reasoning was applied in the analysis of the procedure. This was done through the field experiments and processing resulting in point cadastre database of the sample area. Whiles testing, the procedure was assessed at every stage based on the requirements. Conclusions were based on inductive reasoning and thus resulted in the recommendations.

1.9 Thesis Outline

The research is structured into six chapters and presented in the order shown in Figure 1-2: Thesis Flow Diagram, below. Introduction to this research as presented in this chapter (shown in grey) is followed by the Background, Requirements, Design, Prototyping, Analysis and conclusion in that order.

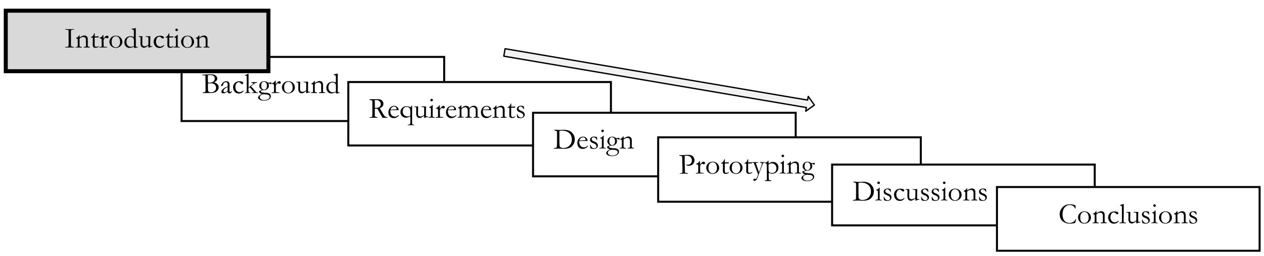

Figure 1-2: Thesis Flow Diagram

Further descriptions of the contents of the various chapters are provided in sections 1.9.1 to 1.9.7 below.

1.9.1 Chapter 1: Introduction

Chapter one consist of the background, research problem, research objectives, research questions, research methodology and the thesis outline.

1.9.2 Chapter 2: Background

This chapter explains the theoretical foundations of the study by focusing on the point cadastre mapping and assessment. The chapter further explains the advantages and existing experiences of point cadastre from available literature.

1.9.3 Chapter 3: Requirements

Chapter three involves the compilation and validation of requirements of building and maintaining point cadastres. The requirements were drawn from some experts in land administration and cadastral surveying.

1.9.4 Chapter 4: Design

Having established the requirements needed for the building of a point cadastre, this chapter presents a design and assessment frameworks for implementation and subsequent assessment. The design takes into accounts requirements indicated earlier as well as current available technology.

1.9.5 Chapter 5: Prototyping

In this chapter processes carried out by the researcher in the implementation and assessment of the design is described in detail. Explanations of test of available options regarding base layers, storage devices, mapping devices, cadastral overlays and maintenance together with their assessments are presented in this chapter.

1.9.6 Chapter 6: Discussions

Chapter 6 simply reflects on the earlier chapters with emphasis on chapter five for justifying the component choices made in the final design

1.9.7 Chapter 7: Conclusions and Recommendations

Being the final chapter in this research, chapter 7 revisits the research objective and question to assess whether they have been met. This chapter also provides recommendations for future works concerning point cadastres.

2 BACKGROUND

2.1 Introduction

The first objective of this research which deals with understanding the concept of point cadastres is addressed here in this chapter. This is the second stage in the Thesis Outline as shown in the Structural Flow Diagram shown in figure 2-1 below.

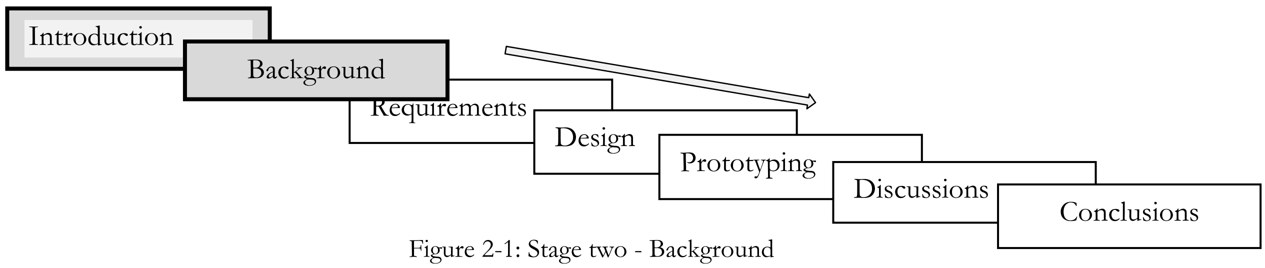

Figure 2-1: Stage two - Background

The chapter is divided into two parts: first is a review aimed at forming a comprehensive idea about point cadastre trials and concepts, including advantages and disadvantages and approaches to building point cadastres; the second part examines the implication when replacing (cadastral) polygons with (cadastrally relevant) points.

The outputs of this chapter are:

- Brief description of which literature search strategies were applied (section 2.2)
- A table showing existing examples of point cadastre, various classes of point cadastre, advantages and disadvantages of point cadastre (Table 2-1)
- A list of requirements for building point cadastre
- A description of existing approaches to building a point cadastre
- Arguments for point cadastres

2.2 Literature Search Strategies

The search strategy for finding relevant documentary sources for point cadastres from grey literature (consultant reports of Kadaster, articles in magazines) has been tabulated in Appendix 4: Search Strategies. The idea of point-based cadastres is referred to as lots-by-dots(Burke, 1995; Home & Jackson, 1997), dots-for-plots, single point cadastre (Haldrup, 2004; Home & Jackson, 1997), or mid-point cadastre(D. C. Fourie, 1994; Home & Jackson, 1997). These were part of the key search terms and the idea of representing spatial features with single point (dots) in a cadastre served as the basic guiding elements for choosing literature for this study. Articles the researcher had access to from the onset were primarily reviewed and later their authors were used as search terms. The requirements for searching were articles that have any of the search terms anywhere in their text. Even though the point cadastre concept is not exactly new, few materials in terms of literature is available and even these comes without much details. A number of articles that possess the slightest relevance to point cadastre were selected and initial scans revealed some closely related keywords that were subsequently used as alternative search items. Among these are “informal settlements” “land registration” and “developing countries” and these were combined with other keywords for further searches. The search resulted in three books, five papers, one PhD thesis and one report. Science direct, Amazon books website, ITC library catalogue and google website were the sources of materials found. Relevant

documents were then properly scanned by searching through the text to identify the related articles. Some useful articles were also obtained from the references columns of papers under consideration.
Details of the search strategies and results are presented in appendix 4. Table 2-1 also provides a summary of relevant information found from literature.

2.3 Existing Situation on Point Cadastre

The concept of point cadastre has been around for quite some time but very few documents can be found concerning views and experiences on this subject. Unfortunately, the little available also provides little details that makes it very difficult to acquire enough information for in-depth analysis. However, bits and pieces of information gathered from literature provide adequate understanding, implications and the methods employed in developing this concept. From literature point cadastre is said to be comparable in nature to the usual cadastres but only differ in the representation of the spatial units. In point cadastre parcels, apartments and buildings are represented by single points as against the well-known polygons representation applied in the normal cadastres.

The use of this method in mapping applied in countries like Thailand, Philippines, Honduras, Indonesia (Home & Jackson, 1997), Pakistan (Burke, 1995) and South Africa (D. C. Fourie, 1994) recorded quite impressive results in terms of efficiency in construction and maintenance; and resource requirements. For example (Home & Jackson, 1997) claims that Padco Incorporation project in San Pedro Sula (Honduras) captured 30,000 rural and urban plots within 4 months at 120,000 dollars less cost using point cadastre. In Denmark the point cadastre concept is applied and the points serve as key- identifier rather than for land parcels and this they claim will eventually become an important contribution to spatial data infrastructure of the country (Haldrup, 2004).

Point cadastre has several other advantages apart from the acclaimed time and cost savings. One important advantage is the potential to upgrade into a polygon based cadastre at a later time when suitable drivers and finance are available (D. C. Fourie, 1994; Griffith-Charles, 2011; Lemmen, 2010; P. van Oosterom, et al., 2006). However (D. C. Fourie, 1994) explains that this method also allows for easy downgrading of titles. This really makes it flexible and can therefore be used as a quick and cheap starter, making it suitable for developing countries, with very little cadastral coverage, post conflict areas and countries with large scale informal settlement (Lemmen, et al., 2007). Boundaries of the parcels the points represents could be surveyed later and possibly link to the existing address system based on the points. According to (Home & Jackson, 1997) point cadastre database is smaller in terms of storage size with no geometry and topology problems thereby making it less expensive and easy to manipulate (Burke, 1995). In addition to reducing the number of field measurements and avoiding boundary adjudications, point cadastre can therefore be built quickly and also serve as basis for dispute resolution in future (Home & Jackson, 1997) rather than waiting on the snail-pace adjudicated boundary-based cadastres.

In the 1990s (Home & Jackson, 1997) cited the lack of political will as the major factor that plays down against the concept. They pointed out that in spite the numerous advantages of point cadastre, aerial surveys is much preferred. (Lemmen, 2010) also noted that point cadastre is half-baked and transforming later into topologically structured polygons adds up to cost.
A number of requirements/indicators and approaches for building a point cadastre were also identified from literature. Some of these have actually been used but others are only known in theory. These have been outlined in details in sections 2.4 and 2.5

Practical examples of point cadastre	Advantages/ Disadvantages	Requirements for developing point cadastre	Approaches to developing point cadastre
Evidence of application in: -Thailand -Philippines -Honduras -Indonesia -Pakistan (Burke, 1995; Home & Jackson, 1997) -South Africa (D. C. Fourie, 1994; Rugege & Maleka, 2008) -Denmark (Haldrup, 2004)	*Advantages* -Time and cost savings(Burke, 1995; Griffith-Charles, 2011; Home & Jackson, 1997) -Flexible: ability to easily upgrade into a polygon based cadastre(D. C. Fourie, 1994; Lemmen, 2010; P. van Oosterom, et al., 2006) -downgrading of titles(D. C. Fourie, 1994) -point cadastre database is smaller in size with no geometry and topology problems(Burke, 1995; Home & Jackson, 1997) -basis for dispute resolution(Home & Jackson, 1997; Lemmen, et al., 2007) *Disadvantages* -considered half-baked(Home & Jackson, 1997; Lemmen, 2010) -lacks political backing	-Spatial units must be represented by a dot positioned on the spatial unit(Home & Jackson, 1997; Lemmen, et al., 2007) -This must be geographical positioned well if possible. -It should be made possible to match one right to one or many properties(Lemmen, et al., 2007) -A unique identifier is required for each dot. The identifier must be unambiguous throughout the database(Burke, 1995; D. C. Fourie, 1994; Haldrup, 2004) -It should be possible to upgrade into the polygon-based (Griffith-Charles, 2011; P. van Oosterom, et al., 2006) -The point cadastre must fit into the National Coordinate System(D. C. Fourie, 1994) -Adjudication issues must be left for neighbours to solve(Haldrup, 2004; Home & Jackson, 1997) -Require local participation and control(Home & Jackson, 1997) -GPS check on orientation, scale & datum is important(Home & Jackson, 1997) -The system should allow for easy updates (D. C. Fourie, 1994)	*Ground Survey method:* -suitable in slums -collecting data requires field contact with handheld GPS -sketches of parcel are attached together with other range of information. -extents of the parcel may be described textually and attached to the data. (Burke, 1995; Griffith-Charles, 2011; Home & Jackson, 1997; Lemmen, 2010) *Desktop method:* -applies in any kind of condition. -basic requirements are satellite imagery or aerial photographs. -approximate centroid coordinates may be taken off the photograph or satellite. -little or no contact on ground is required (Burke, 1995; Griffith-Charles, 2011) *Combination method:* -combination of the general boundary and the midpoint methods using a handheld GPS -mid-point coordinate is obtained and boundary description related to it (Rugege & Maleka, 2008)

Table 2-1: Secondary Data Summary

2.4 Requirements for Building Point Cadastre

Available literature advocating for point cadastre emphasises that when adopting this concept, there is the need to recognise that recording the rights to these holdings is the main point of interest and not the position of the exact boundaries (Home & Jackson, 1997; P. J. M. van Oosterom, Lemmen, & ... 2011). In view of this the indicators/requirements found emphasises very little on accuracy but rather on cost, speed, scalability and ease of use. To buttress this observation, the requirements deduced from available literature have been outlined below:

- Spatial units including parcels, apartment and buildings must be represented by a dot positioned anywhere on the spatial unit or just outside the unit. This must represent the geographical position as close as possible (Burke, 1995; Home & Jackson, 1997; Lemmen, et al., 2007).
- The accurate position of the land right is needed not its boundaries (Home & Jackson, 1997; P. J. M. van Oosterom, et al., 2011)
- It should be made possible to match one right to one or many properties (Lemmen, et al., 2007).
- A unique identifier is required for each dot. The identifier must be unambiguous throughout the database (Burke, 1995; D. C. Fourie, 1994; Haldrup, 2004).
- It should be possible to upgrade the point cadastre database into the polygon-based cadastre without much trouble (D. C. Fourie, 1994; Griffith-Charles, 2011; Lemmen, 2010; P. van Oosterom, et al., 2006) .
- The point cadastre must fit into the National Coordinate System for easy integration into the formal LIS and for easy absorption of complimentary data (Burke, 1995; D. C. Fourie, 1994; Home & Jackson, 1997; Lemmen, 2010).
- No attempt should be made to adjudicate boundaries when building the point cadastre. Adjudication issues must be sorted out by neighbours themselves (Haldrup, 2004; Home & Jackson, 1997)
- Ideally, local participation and control must be encouraged. Occasionally, GPS check on orientation, scale & datum is important (Home & Jackson, 1997).
- Boundary descriptions and other spatial information must be introduced gradually. The system should allow for easy updates(Haldrup, 2004; Home & Jackson, 1997).

2.5 Existing Approaches to Building a Point Cadastre

Three main approaches to building a point cadastre are categorized into 'Ground Survey' Approach, 'Desktop' Approach and the 'Combination' Approach. Generally, all categories apply procedures already known and used in polygon-based cadastres. For example the identifiers applied to the points in the systems are unique per household among the various approaches. Applying the block strategy is also common and this involves the division of the areas into smaller blocks to prevent errors in one part of the system adversely affecting the records of other areas. All the various systems allow the geo-referencing of every household by one point with the range of information attached. However the mode of data collection and mapping techniques differ slightly and these are explained below:

2.5.1 Ground Survey Approach

This approach is typically suitable in slums where there are very small house holdings which are also not well organised. Usually tenure relations are considered high priority in the application of this method and collecting this data requires contact with the people. Mostly handheld GPS is used for collecting the spatial data. In communities where monuments are required, they are placed about one metre from the door of the dwelling. Survey pegs or stakes are sometimes used when it comes to plot surveys. These monuments are then surveyed and remain in place to represent the actual position of interest. A sketch of the size and shape of the parcel or dwelling is also attached together with other range of information. Sometime the extents of the parcel is described textually and attached to the data.(Burke, 1995; D. C. Fourie, 1994; Home & Jackson, 1997).

2.5.2 Desktop Approach

The desktop approach applies in any kind of condition. The basic requirements of this method are hard or soft copies of very high resolution satellite imagery or aerial photographs. The approximate centroid coordinates for the parcels, which may be taken off the aerial photograph or satellite image are then assigned unique ids. Although, single points are expected to be in the centres, positions within its areas (or volumes) are also accepted. Little or no contact on ground is required and output can hardly be verified. This provides very fast results that can also take on board attribute information relating to the individual points generated. (Burke, 1995; Griffith-Charles, 2011)

2.5.3 Combination Approach

This method is a combination of the general boundary method and the midpoint method using a handheld GPS. The general boundary method usually applies lower precision surveys usually not referenced to beacons and based on boundaries agreed upon by the neighbours. In the 'mid-point' method a single point in the centre of a property marked by a stake is registered and could be maintained by the Surveyor General's. Using the house as the physical evidence, a mid-point coordinate is obtained and boundary description is related to it. Relating to point cadastres, a low precision GPS is employed to collect first-hand information from the field and this combined with points properly positioned on the objects. (Rugege & Maleka, 2008). This therefore combines the strengths of both the 'ground survey approach' and the 'desktop approach'.

2.6 Overview – Polygon-base Versus Points-based Cadastres

According to (Kaufmann & Steudler, 2001), Professor Jo Henssen defines Cadastre as

"A methodically arranged public inventory of data concerning properties within a certain country or district, based on a survey of their boundaries. Such properties are systematically identified by means of some separate designation. The outlines of the property and the parcel identifier normally are shown on large-scale maps which, together with registers, may show for each separate property the nature, size, value and legal rights associated with the parcel".

Cadastral data therefore holds a variety of data including technical data for positional reference, value as base for land taxation and current land use that allows for planning; Legal data for ownership data and encumbrances; and additional data that are neither technical nor legal (e.g. Postal address) (Navratil & Frank, 2004). As already explained, the use of one point (preferably a mid-point) for each household (termed point cadastre) is a potential replacement for the usual polygon-based cadastral by avoiding the laborious surveying of all boundaries of parcels and eventually ensure less cost and faster output. Point cadastre is capable of providing the technical, legal and additional data required of polygon-based cadastral data.

The basic task of a cadastre is to give answers to the questions 'where?' and 'how much?' usually asked of cadastral units. For point cadastres to be considered worthy replacement, attempt should be made to answer these questions. In answering the question 'where', there is the need to employ the use of survey equipment that can at least provide a check on orientation, scale & datum of the point cadastre. The choice of survey equipment must be carefully done to avoid excessive cost that will eventually defeat the goal of point cadastres. For example the some handheld GPS has great potential to provide fairly accurate point cadastre orientation at an affordable cost. The question of "how much" may be downplayed as the idea of point cadastre is not envisaging land as collateral. Like The English general boundary system point cadastre (if the situation desires) may only guarantee titles but not the precise extents of the holdings.

2.7 Concluding Remarks

Among all papers that describe the concept of point cadastre, only two provide details for developing it. This is an indication that the research has been predominantly conceptual and not operational. The advantages associated with the use of point cadastre were clearly spelt out by all the papers but very little were mentioned about the disadvantages. The approaches to building point cadastre are described in a quite similar way and are all based on nine underlining requirements. In spite of that the concepts of point cadastre has a long history very few countries, particularly from the third world, has seen its application. Having gone through the literature, an overview of replacing polygons with points in cadastres was also presented.

3 REQUIREMENTS

3.1 Introduction

Chapter 2 identified the requirements and approaches to building point cadastres. This resulted in the identification of nine requirements and these are outlined in section 2.4. This chapter 3, the aims to renew and summarize additional requirements based on practical experience of land administration and survey experts. This will answer research question number 3 - What are relevant and pragmatic design requirements for building a point cadastre and what are relevant and pragmatic indicators to assess a point cadastre? This chapter is the third stage of the research, Figure 3-1 and presents the outcome with requirements of chapter 2 in mind.

Furthermore, the methods used in the primary data acquisition of the requirements are discussed and together with findings are presented in this chapter. These include focus group discussions and questionnaires.

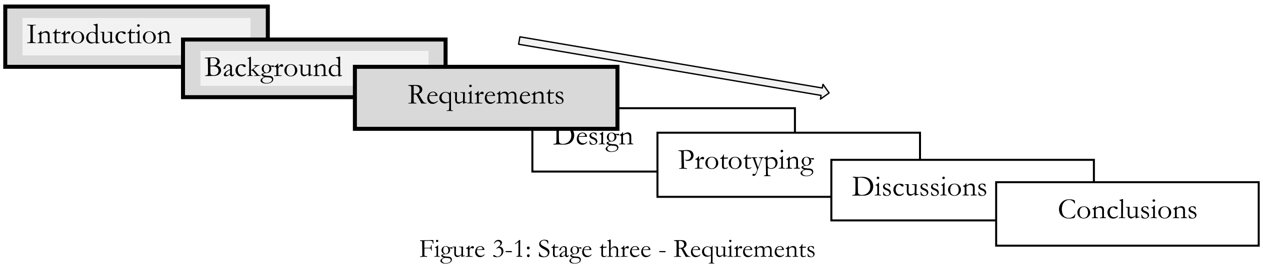

Figure 3-1: Stage three - Requirements

3.2 Primary Data Acquisition

The qualitative data on crucial conditions and requirements for building point cadastres were collected through two separate discussions. These involved practitioners who have been directly associated with point cadastre projects and also have been involved in strategic decisions about re-packaging point cadastres for use in developing countries. The people who took part in the discussions were mostly staff of Kadaster International in The Netherlands. Conclusions drawn from the discussions in terms of requirements for developing point cadastres were validated using questionnaires responded to by some land experts from some key international organisations.

3.2.1 1st Focus Group Discussion

A three member meeting involving one staff member of Kadaster International, a staff of ITC and the researcher was a first step. The staff member had been part of a team seeking ways to make pro-poor land administration a reality in some African countries. He is consulted on his expertise with cadastre and is therefore abreast with the processes towards the design and adoption of point cadastre in Guinea Bissau. He is therefore considered a representative practitioner.

The discussion was conducted informally in a manner comparable to a non-directive interview. In this way the researcher was privileged to unexpected information relating to the requirements and approaches to building a point cadastre. This style actually proved very useful in this study as several issues which hitherto were not considered by the researcher came up for discussion. The discussion lasted for one hour 15 minutes and a research diary was kept throughout to document notes and observations. Notes taken during the discussions were then coded manually using the thematic approach.

3.2.1.1 Findings from 1st Focus Group Discussion

Among the data that was collected in this discussion issues bordering on requirements and technologies are of much interest to the researcher. Suggestions on the requirements for choosing tools and processes for building and maintaining point cadastres were closely linked to issues on cost, speed, accuracy, flexibility, scalability and ease-of-use. A summary of the outcome of the coded interactions and the supporting statements are tabulated as shown in Table 3-1 below.

Code	Supporting statements
Cost	Funding issues must be considered as well Cost of process should be assessed Cost must be calculated- whether paper base or otherwise Base Layer may be affordable satellite image
Accuracy	Level of precision of GPS to apply is not known The point cadastre should be suitable for planning & execution of plans Point cadastre should be accurate enough to execute planning schemes Accuracy & precision of applied mapping device should be enough to execute plans in field
Speed	Should be quick and simple Parcel-based cadastre takes too long
Ease of Use	Apply tool that require just basic training for users Should be simple for all manner of persons Point cadastre should be within the reach of local expertise Point cadastre should be fully controlled by locals Should be very easy for users Consider what fits for the purpose at a given time Should be possible to map in the field Point cadastre should be very simple & easy to use
Flexibility	Innovative approaches could be tried Map should have link with GPS Should be flexible enough to use in several countries. Should support a combination of dots and lines Should be possible to easily include administrative data Consider when newer version of (Google) images comes should be able to absorb all forms of administrative data Should be able to accommodate existing administrative data Addition of existing parcel sketches may be considered Paper-based should eventually become digital Should support AutoCAD docs Pictures of buildings may be included
Scalability	Should develop into multipurpose SDI in future May be aggregated even unto servers for internet accessibility Should be good to serve several cadastre organisations.
Applicable resources	Lack of basic structures should be considered in choice of equipment Consider capacity of developing countries May be paper based at the early stages Importation of new equipment involves training and maintenance

	Point cadastre should be within the reach of local expertise
Equipment and software	Lack of modern equipment should not hinder Point cadastre building Lack of modern equipment in developing countries Consider simple tools like 'ipad' Use of GPS required for easy data collection Use of GIS software required Should be suitable within older versions of computers
Parcel identification	Parcel identification method should cater for future additions Parcel identification procedure needs critical attention
Base layer	Google images may be worth applying Base Layer may be satellite or Google images
Coordinate System	Consider coordinate transformations into national systems
Maintenance	Consider fast and cheap updating processes Backup strategies must be adopted May utilise field mapping tool for both spatial and administrative data collection
cadastral overlay	Require dots on spatial units shown base layer

Table 3-1: Summary Results – 1st Focus Group Discussion

In conclusion, the group discussion helped to explore the issue of point cadastres in depth and also a set of requirements were derived which were further validated in this research.

3.2.2 2nd Focus Group Discussion

The Zwolle office of Kadaster International organised what they termed a 'pressure-cook' meeting to discuss the technicalities involve in developing a functioning point cadastre for Guinea Bissau. The meeting was attended by five key personnel in the area of management, surveying/mapping and ICT of the Zwolle branch office of Kadaster international. For me, it was good opportunities to have a cross section of players contribute ideas in a single forum.

The meeting took the form of focus group discussion and lasted for about one and half hours with a brief tour of the office. The discussion which involved seven people including the researcher was well moderated by a manager of the Zwolle office. Among the key issues discussed were the possible benefits of point cadastres in developing countries especially; likely problems in point cadastre; how to develop a point cadastre; and technology to apply. Almost every single item discussed was directly related to the research and very beneficial as well. Issues concerning inputs and processes of building point cadastres was adequately analysed with all available options brought to the fore.

Although, group discussion is said to be difficult to generalize from the results, it has been accepted as a tool to understand the perceptions and experiences of people with similar knowledge and experience (Kumar, 2005), and in this case this method encouraged open and frank discussions (Gray, 2004) that eventually resulted in interesting ideas from the participants. The keeping of a research diary to document notes and observations rather than using a tape recorder, as generally preferred on the day, contributed to the openness of the discussion.

3.2.2.1 Findings from Focus Group Discussion

It was generally agreed that point cadastre has a potential in serving the needs of countries with little cadastre coverage. In view of this, the moderator indicated that all techniques to be considered for building point cadastres should be based on fit-for-purpose and not necessarily accuracy. He later define the term 'Fit-for-purpose' as a quick, cheap, easy–to-use, low profile or not too complex people-parcel relationship records for decision making.

Upon some deliberations a 1:10,000 scale paper map and at much bigger scale in the cities was deemed ok but a digital method was rather preferred if possible. The content of the map is to be similar to that of a 1:10,000 topographic maps and comparable to bigger scale maps in towns and cities. However for the sake of cost and time the height component is to be ignored for the meantime.

Members are of the view that it is very essential to build the point cadastre with a reference coordinate system in order to ensure compatibility with data from other sources. Again the issue of unique identification system adopted should be meaningful and consistent for every point introduced to have easy identification and for referencing. Some options including geo-coding and Kadastre international systems of parcel identification were discussed but there was no consensus on which one to adopt.

The issue of providing ground control point were also considered but it was agreed that this should not be done at any high accuracy. With GPS some controls could be provided in the centre of town purposely for rolling out designs from the town planning office. It was also agreed that initially these controls may be without heights. Therefore the application of handheld GPS was decided to be just ok because of cost of high grade GPS and its ease of use. However the accuracy of the preferred equipment should be fairly reasonable and should be as precise as possible.

Concerning the image base layer, quite some time was spent assessing the quality and cost of satellite images particularly for achieving the goals of point cadastre. The use of satellite image as a base layer was accepted as important component and was explain that it will enhance the ease of use principle of the point cadastres. The satellite imageries that came up for discussion were geo eye and worldview 2. These two were preferred basically because they are high resolution images.

The base IT infrastructure in terms of hardware systems and software to apply was one of the important issues discussed. The IT Infrastructure in this context refers to the foundation upon which the point cadastre's specific systems are built. These include everything that supports the handling and processing of information for building and maintaining point cadastres. The mapping device to be applied was settled on a cheap handheld GPS that have additional functionality that promotes in field mapping in order to at least reduce processing time.

Like the 1st group discussion, prominent requirements identified were issues concerning speed, cost, and ease of use, flexibility, scalability and accuracy. Other key issues that were discussed included map scale, unique parcel identification numbering system, map content, image base layer, ground control points, base IT infrastructure, reference systems and cloud computing. This discussion really opened up several options for the researcher to consider.

3.2.3 List of Requirements

Key issues from both the primary and secondary data highlights 12 fundamental requirements expected of point cadastres. These are listed in no particular order in Table 3-2 below and further explanation provided in section 3.3.

No	Requirement	Description
1	Application of available Resource	Must heavily depend on available resources to build
2	Coordinate Reference System	Must fit into the national reference network
3	Points representation of Parcels	Cadastral overlay must basically be single points
4	Parcel Visualisation	Parcels represented by points must be displayed pictorially
5	Point-attribute data linkage	There must be a link between points and attributes data sets
6	Display/Query/ Maintenance	Must be possible to display output and query system
7	Ease of Use	It must be easy to build and maintain
8	Cost	It must be as very affordable to build and maintain
9	Time/Speed	It must be complete in the shortest possible time
10	Flexibility	It must be usable by many stakeholders
11	Scalability	It must have the ability to increase in coverage
12	Accuracy	It must be fairly accurate for planning purposes

Table 3-2: Requirement & Description

3.2.4 Additional Primary Data using Questionnaires

As part of data collection exercise from a primary source for the purpose of validating the requirements, questionnaires comprising of closed ended and open ended questions were administered to some experts. Same questions were sent to all participants using the online tool, 'Survey Monkey'.

To ensure that only the invited persons/organisations took part it was necessary to use a password made available only to the targeted group to access the survey on line. Requirements terms were adequately defined in the survey to ensure clarity in the use of these terms regarding this research.

3.2.4.1 Justification for the Questionnaire

The decision to use a three question online survey was purposefully opted for rather than an approach using longer multiple choice questionnaire and or interviews. This was the best option available to the researcher since the respondents mainly from FAO, FIG, UNHABITAT, World Bank and ITC were to be contacted within a very short period. The approach was based on the following considerations:

- Experience has shown that long questionnaires usually receive fewer respondents than shorter one especially when administered online. Therefore keeping the questionnaire to three was purposely to motivate respondents to answer them
- Although questionnaires have a level of researcher's imposition especially in deciding what is of importance to appear, large amounts of information can be collected from a large number of people in a short period of time and in a relatively cost effective way. To address the shortcoming mentioned earlier, respondents were given the opportunity to fully express their thoughts in the third question.
- Results of the questionnaires can us quickly and easily are quantified by a researcher even though it is difficult to validate. Quantification of the results was important for the ranking of the requirements and was therefore easier by including close ended questionnaires.

3.2.4.2 Selection of Target Group

A set of requirements were used for the selection of respondent groups. These requirements were

- Level of (administrative) operation: World-wide
- Type of body: Non-governmental:
- Type of decision-making bodies: Policy, (strategic) planning, financing bodies, Resource management, Environmental protection
- Research area: Land Administration

On the basis of these parameters several relevant bodies can be identified and included in the study. However, the researcher managed to have access to a few due to time constraints. These are FAO, FIG, UNHABITAT and World Bank and ITC. (Roberge & Christensen, 2008) confirmed that the aforementioned organisations have played various roles in land administration, cadastral systems, and good governance in the last decade. They have also been part of many workshops, expert meetings and conferences to address land administration issues to promote access to land and registration of rights to contribute to poverty reduction and economic development. These are assurances that the selected organizations can be trusted of having land administration expects with vast experience in the field.

3.2.4.3 Findings from Questionnaires

A total of 15 responses were received and the results represented in Table 3-3 below showing the requirements as well as the total votes they received from the respondents. Every single respondent agrees that cost is requirements to consider, and therefore received 100% support by way of votes. Meanwhile only 38.5% thinks that accuracy is of essence. However ranking them produced slightly different results. 46.2% ranked 'ease of use' number one and 53.8 thinks 'accuracy' is of least importance..

Requirements	**Percentage votes received**						
	Worthy Requirements	**Level of importance (1st is most important…….6th is least important)**					
		1st	**2nd**	**3rd**	**4th**	**5th**	**6th**
Cost	100	33.3	***33.3***	26.7	6.7	0.0	0.0
Ease of use	93.3	***46.7***	13.3	26.7	6.7	0.0	6.7
Flexibility	86.7	0.0	6.7	20.0	***26.7***	35.7	13.3
Accuracy	46.7	0.0	20.0	0.0	13.3	14.3	***46.7***
Scalability	73.3	0.0	0.0	6.7	26.7	***42.9***	26.67
Time/Speed	86.7	20.0	26.7	***20.0***	20.0	7.1	6.7

Table 3-3: Summary Results from Questionnaire

The bar charts (Figure 3-2) below give a good impression of percentage of respondents' confirmation to the worthiness of the requirements. From the responses, the requirements can be confidently considered good enough in relation to building and maintaining point cadastres. In ranking of the assessment requirement, ease of use came up tops but had only 14 respondents supporting its inclusion. This is possible in the sense that question 2 which has to do with the ranking was responded to by all. In spite of being ranked 1 and therefore the most important, 47% of the respondents, 33% and 20% thinks that cost and Time/Speed respectively should be most important. This kind of trend was realised throughout the results given that even 20% thinks that Accuracy which ended up 6th in the ranking should be considered the 2nd most important. Percentage responses leading to the ranking order are displayed in a group bar chart shown in Figure 3-3 below.

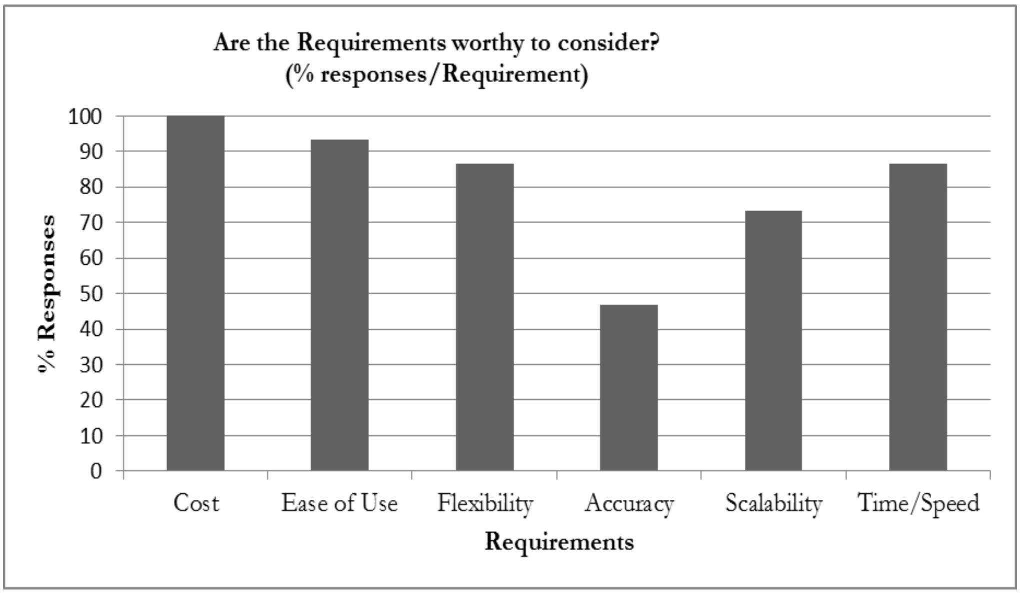

Figure 3-2: Requirements vs. % respondents that agree to choice of requirement

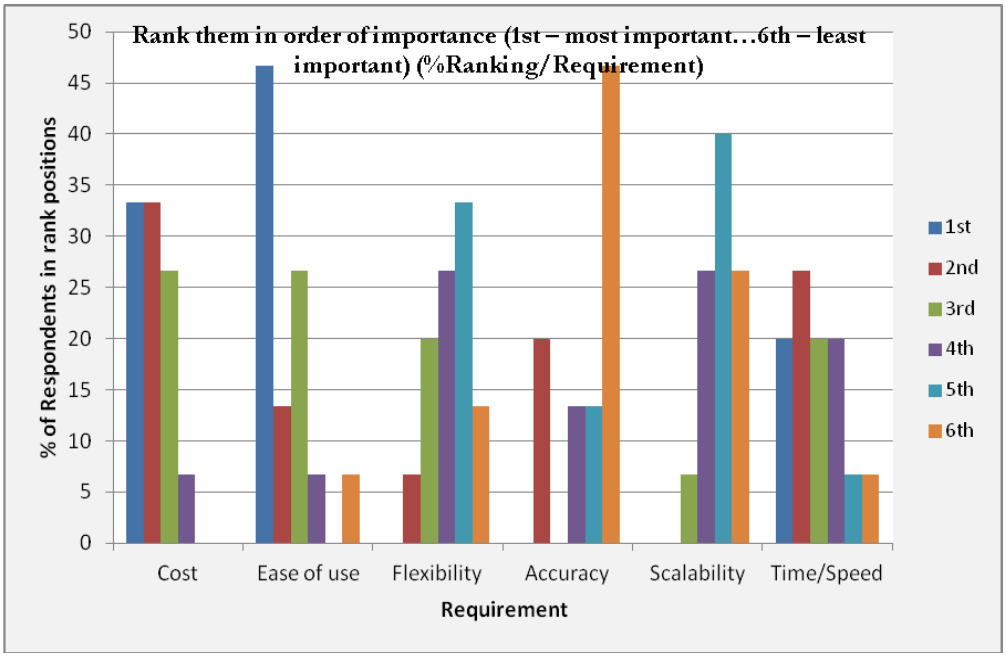

Figure 3-3: Requirement vs. % in ranking order

Considering that the outcome of the ranking are closely knit together, and even 20% of the respondents support Accuracy as the 2nd most important, then all requirements deserve some attention depending on the purpose and available resources for developing the point cadastre. This diversity in the ranking order could be as a result of the diverse background and direction of the organisations the respondents belong. Few other suggestion were proposed by the respondents but had been catered for in this research except the issue of 'legal definition'. However it is not the intention of this researcher to go into that.

3.3 Summary of Requirements

The findings from the group discussions were categorized into respective themes (codes). Notes and report on the group discussions which were prepared earlier had been edited with the key points presented in section 3.2. The findings from the discussions together with results from the questionnaires are further explained in coming paragraphs.

As a result of analysis of the data collected in relation to the specific forms and functions of the requirements; Cost, Ease of use, Flexibility, Accuracy, Scalability and Time/Speed are regarded as performance related. However, it is not feasible to achieve all these in one go. There was therefore the need to have them ranked in an order from most to least importance which was done using the questionnaires served to land administration experts.

Since selection of components in the building of point cadastres in this research was done by trying some options based on the six requirements mentioned a clear definition of them helps avoid delays and misuse of resources due to incorrect, inaccurate, or excessive definition. These are shown in Table 3-4 with their definition and rank in terms of the level of comparative importance attached to each of them. The ranking positions were decided upon based upon rank most respondent prefer for each requirement. Considering results in Table 3-3, attempt is made to derive optimal ranking positions in stages as some requirements were tied to a single position. Overall positions assigned were decided by considering requirements with the best percentage value. Where there are equal values at same positions, they were separated by considering the immediate next position values. For example among all the requirements that got 1st ratings, 'ease of use' comes out tops with 46.7%. Also the second is a tie between 'cost' and 'speed' but was decided on 'cost' because it has better value in the 3rd rating.
The results are consistent with the outcome of the group discussions considering the emphases placed on them by the participants.

Requirement	Assessment Requirements	Definition	Rank
7	Ease of use	refers to the level of technical/specialized capacity to build and maintain the point cadastre	1st
8	Cost	refers to the costs of technical equipment, human resources, supplies, etc., in producing and maintaining the point cadastre database	2nd
9	Time/Speed	refers to the time required to initially develop and maintain the point cadastre	3rd
10	Flexibility	refers to the capacity of the point cadastre to be used across different agencies by many stakeholders	4th
11	Scalability	refers to the ability of the system to be extended for use at regional and national levels (i.e. increasing the types of data collected, spatial coverage, allowing for concurrent users)	5th
12	Accuracy	refers to spatial accuracy of the points collected (i.e. the closeness of the positions of objects in the point cadastre to the positions on ground)	6th

Table 3-4: Assessment Requirements

3.4 Data Collection Limitations

Generally the data collection processes were smooth. However there were some obvious limitations beyond the control of the researcher. These include the researcher's inability to secure more iparticipants due to the fact that the point cadastre concept is not a very familiar subject. The discussions were not recorded and therefore very tiny information may have been missed in the course of writing down the notes. Quite unfortunately the researcher could not have access to experts from developing countries to engage in an interview or discussion. However the validation which was done by experts with vast experience included persons from developing countries and others that have worked there.

3.5 Conclusion

In all twelve general requirements of points cadastres had been generated. Six of these requirements are related to the building of a point cadastre. These are: application of available resources; use of national reference coordinate system; points for parcels representation; cadastral overlay should also enhance visualisation; application of unique parcel identifier; and application of storage, display and query device. Six other requirements for the assessment of point cadastres realised are Ease of Use, Cost, Time/Speed, Flexibility, Scalability and Accuracy in order of most important to least important. The assessment requirements are ranked in order of importance through questionnaires administered to some organisations including FAO, FIG, UNHABITAT, ITC and World Bank.

In the next chapter, requirements related to the building of the point cadastre will feature in the components design. Options available for each component will then be tested based on the assessment requirements in chapter 5.

4 DESIGN

4.1 Introduction

This chapter provides the fourth stage of the research, namely the Design (Figure 4-1). The outcome of the design then leads to stage five – Prototyping.

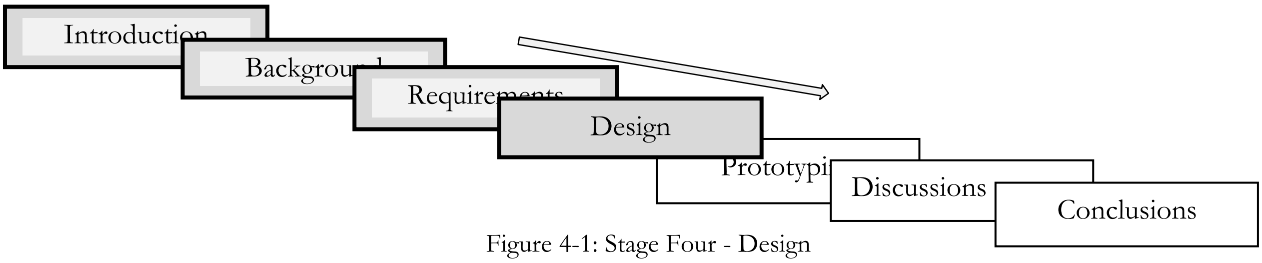

Figure 4-1: Stage Four - Design

This chapter describes the design and assessment of the procedure for building and maintaining point cadastres. The design integrated the requirement indicated and takes into account available tools at the disposal of the researcher. An assessment of component options using an assessment framework is described in section 4.4 for the prototyping in chapter five. This chapter therefore answers research question three and also serves as basis for dealing with research question four.

4.2 Design Components

The design method for building and maintaining point cadastres in this research is component based. This means that components are designed to meet each requirement at a time. This began with the recognition of the requirements that leads to finding components which meet the point cadastre building requirements. Considering the requirements listed in section 3.2.3 four physical components involving mapping device, storage device, satellite imagery and cadastral overlay are identified to meet the components requirements.

Specific options of these components are also expected to meet the assessment requirements - Cost, Ease of use, Flexibility, Accuracy, Scalability and Time/Speed (Table 3-4). Therefore, a number of options available to the researcher for each component were assessed during the prototyping and presented in chapter 5. Table 4-1shows is a summary of the requirements, their related components and number of options tested in the prototyping.

No	Requirement	Design components	No: of options
1	Available resources	Resources available to researcher	
2	Coordinate reference system	All input data must be projected to the local reference network (In Netherlands - RD_ new)	1
3	Points rep. of parcels (in field or office)	Field Survey with GPS mapping Devices On screen digitisation	3 (GPS)
4	Parcel visualisation	Apply base images (satellite)	3
5	Points - attributes data linkage	A unique identifier to serve as a link between all attributes and points	4
6	Storage/display/query/ visualising device and maintenance	A database management system (GIS software) storage Device	2

Table 4-1: Components designed to meet requirements

The components are designed to meet specific requirements but some provide additional solutions useful in the design. In relation to specific requirements, the following subsections describe the component options available to the researcher.

4.2.1 Application of Available Resources

The first requirement of components identified in point cadastres is the application of only available resources. This was later realised in the research as one of the most important requirements. Physical components needed to meet the requirements include GPS mapping device, satellite image and GIS software. Other components are unique identifier and local reference network.

In order to realise this requirement, only options readily available to the researcher were considered in this research. In terms of satellite images, Quick bird, ikonos, and Google images were available for use. To get the images ready for use in the point cadastre, some image processing techniques were needed. Therefore Erdas imagine, Ilwis and Envi-idl image processing software available were options considered in the design. ArcGIS, Quantum GIS and GeoMajas were also included in the design as a storage, query and display facility. Trimble Juno SD handheld, Garmin 12XL handheld and Leica 1200 GPS receivers (photo: Appendix 7) and their respective software are also option applied in the design because they were available.

4.2.2 Coordinates Reference System

Regarding the second requirement, local coordinate reference system is applied in the design of the point cadastres. In this research, all data inputs were projected onto 'RD_New' which is the coordinate reference system here in the Netherlands – pilot area. A coordinates system defines how geographic data should be related to real location on the earth's surface. The system may be global or local. Local is preferred in this process because point cadastres have a goal of complementing existing cadastres and later develop into a SDI and therefore adopting a totally new coordinate system will bring on board transformation issues later. In this particular pilot area, the reason to apply this system is that existing maps (cadastres) are already based on the local coordinate systems. Therefore introduction of new cadastral maps in a (local coordinate) system which is familiar and already understood by the users is encouraged rather than adopting a new one that is likely to delay the building process in point cadastres.

4.2.3 Points Representation of Parcels

A basic component of cadastre is a cadastral overlay that delimits the current status of properties. The individual building block for the overlay is the cadastral parcel, within which unique interests are recognized. In a point cadastre parcels are represented by points and attached to unique identifiers through which attribute data are related. Also in point cadastre building, time, cost and ease of use are of essence and with some level of accuracy preferred. Therefore two point creation methods – field survey and on-screen digitising were considered to meet requirement 3. These approaches are used for creating points as overlay needed for building point cadastres. Both field data collection and on screen digitising are procedures that complement each other towards achieving a fairly accurate, fast and easy of use point cadastre.

Leica 1200, Trimble Juno SD and Garmin GPS 12XL available to the researcher are options used in the field survey. Digitising onscreen is made possible with computers and options of geodetic controlled and uncontrolled base layer (satellite image) were drafted in for assessment in the design.

4.2.4 Parcel Visualisation

The difficulty in understanding only points displayed in a point cadastre map need to be tackled as demanded by requirement 4. To respond to this requirement, satellite imagery was employed in the design to give meaning to the points. Fundamentally, using base layers (images) helps locate the major physical features of the landscape like roads, water features and buildings. This satellite images employed in the design also supports the on-screen digitisation. The base images adopted in this design are high resolution images which offer opportunity for clearer visualisation of properties or parcels including individual slum dwellings. Satellite images are included in the design also because of cost and availability as and when needed as well as where (area of coverage) needed. Quick bird, ikonos, and Google images are the options available for use in this research.

4.2.5 Points - Attributes Data Linkage

The point cadastral system like any cadastral system require a means through which parcels can be linked to their attribute data without any duplications in the system. The key link between parcels and attribute data (usually in tables) is a parcel identifier that usually uses numbers or codes. In order to meet requirement 5 in this research a unique identifier serving as a link between attribute data and the cadastral overlay was considered. The point cadastre is intended to serve several stakeholders and also take on board many tabular land related data. Therefore the unique identifier adopted should stands to serve all the stakeholders together with the data coming in.

Samples of identifiers mentioned by (Kalantari, Rajabifard, Wallace, & Williamson, 2008): Geographic coordinates, Rectangular survey, Map-based, Name-related and Alphanumeric are options adopted and used in response to the requirement. However, they were assessed based on characteristics mentioned by (Moyer & Fisher, 1973) - uniqueness, Permanence, Ease of use, Ease of maintenance and Flexibility in this research.

4.2.6 Storage/Display/Query /Visualising Device

The mode of updating, analysing, querying, visualization and maintaining is of concern in the point cadastre design. This extent to which this requirement is met can potentially promote users' interest in point cadastres. Basically, the point cadastre storage device has the challenge of being an effective and efficient tool for land management and administration. Therefore the inclusion of a GIS component in the design offers a means to meet all functions expected of requirement 6 at one go. The provision of a GIS platform also provides opportunity for easier manipulations including geo-referencing and on screen digitisation.

In this research, two GIS software available to the researcher represents the commercial and open source ranges of software. ArcGIS represents the commercial range; and free/open source QGIS and Geomajas. However, only ArcGIS and QGIS were practically possible to apply in this research.

4.3 Maintenance

Cadastres are dynamic in nature and to make them useful and reliable they require regular maintenance to keep records current. Although it is part of requirement 6 in this research, maintenance affects all components in the point cadastre and contributes by making it up to date. Maintenance consists of 'Change Records' that include information on any additions, modifications or deletions to the data in a specific time period. For this research it involves base images, overlays, attributes as well as other data inputs in the point cadastre.
The maintenance of the point cadastre database will include alterations that have occurred regarding:

- subdivision, partition and amalgamation of landed properties;
- subdivision and amalgamation of buildings;
- conversion of point parcels to polygons;
- rectification of complete error in the position of an interest;
- the case of constructed buildings, buildings with super-structures and extensions, removed buildings, as well as reconstructed buildings;
- alteration of the purpose, of the mode of long term use, and of the addresses of the properties;
- alteration of the data about right of ownership and the other real rights as well as alteration of the data for their holders; and
- rectification of incorrect parcel identifier

These are few errors that are actually dealt with in the field. Maintenance is eventually concluded in the storage device and therefore assessments of this process were linked to the choice of component to meet requirement 6. It should be noted that not all issues listed above were possible to apply in the prototyping in chapter 5.

4.4 Assessment of Components

Regarding point cadastre building requirements (requirements 1-6), various components have been designed to cater for them. However, each component has two or three available options to the researcher that should be assessed for the final design. This section therefore explains the means designed for assessing the available options regarding both inputs and processes for building point cadastres. Here the assessment requirements (Table 3-4) were used to design the framework (Appendix 5). According to (Devillers & Jeansoulin, 2006) the quality of the cadastral data can be categorized as internal and external. Internal is related to the characteristics of the data, starting with the methods of data production (data acquisition, data modelling, etc.) and external is connected to the level of adequacy existing between the characteristics of the data and the user's needs. The internal data quality is mainly assessed in this research.

The assessment framework which provides opportunity for assessing various options within the processes for building and maintaining point cadastres was designed based on the requirements outlined in chapter 3. The use of assessment matrix (framework) is to make it easier to analyse and determine the options that best meets the assessment requirements. When these are well undertaken and freed from subjective elements, it offers a good chance to specify the best design for the building and maintenance of point cadastres. First, an assessment of the inputs and processes of building and maintaining point cadastres carried out will result in both qualitative and quantitative outcomes (refer Appendix 5) which are then translated into simple qualitative terms for deciding on choices. Qualitative ranges of values are used to assess each option as per the requirement used. For easy understanding and consistency, ordinal values of High-Medium-Low are used in this assessment. The choice of input or process was based upon all applicable requirements. With the matrix serving as the guidelines, selections made borders on experience and reasoning. However interoperable possibilities were also considered in the choices.

4.5 Conclusion

This chapter discussed components designed to meet the various requirement (point cadastre building). Resources available to the researcher were used throughout to cater for requirement 1 - Available resources. Using RD_New which is the local coordinate reference system of the Netherlands responds to requirement 2, National coordinate reference system. To meet requirement 3, Points representation of parcels, points creation using GPS or onscreen are considered. Satellite base images provide a means of parcel visualisation in requirement 4. In order to create a link between points to attributes data (requirement 5), unique identifier are proposed as the answer. The last building requirement 6 – needed a device in which the data can be stored, displayed, queried, visualised and maintained. GIS software is therefore used to cater for these. All these inputs are not new to the researcher regarding the basic applications necessary for developing a point cadastre.

However available options of each components outlined in this chapter are applied and assessed in a prototyping environment in chapter 5. For the assessment of the components, a designed framework was applied to record both qualitative and quantitative outcomes.

5 PROTOTYPING

5.1 Introduction

In this chapter a test and assessment of the design are conducted. The aim of this is to describe processes carried out by the researcher in developing and assessing a point cadastre samples. In chapter 4, the design and options were introduced but at this stage of the research (figure 5-1) - Prototyping, the manner in which they are executed or applied are explained. This involves the applications and test of available options regarding base layers, storage devices, mapping devices, overlays, maintenance and assessment. Field data were collected in Enschede, Netherlands; therefore a brief background description of the pilot area is also presented. Parts of research questions 3 and 4 are answered in this chapter.

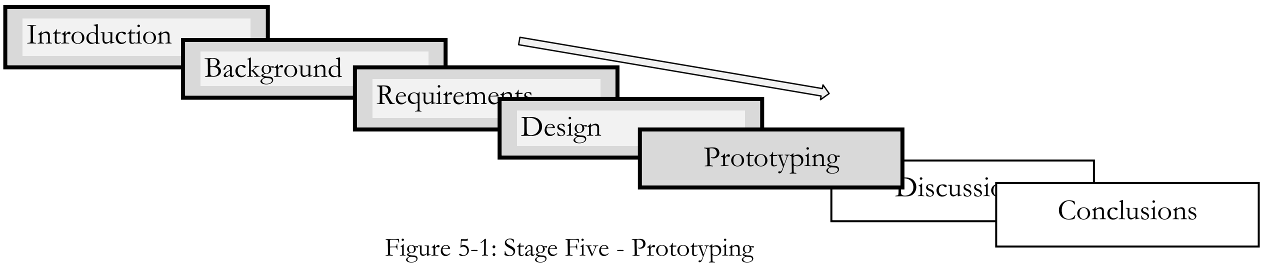

Figure 5-1: Stage Five - Prototyping

5.2 Pilot Areas

As already mentioned, Enschede is the test area and satellites images acquired cover the whole town. For the sake of time constraints on the research a small portions (pilot areas) had to be considered.

The choice of a pilot area for the test was based on proximity, coverage by satellite images and Google images for the production and assessment of the point cadastre. The reason for selecting a pilot area is to test options of developing a point cadastre together with its assessment at the same time. Though the sample area selected is not a true representation of conditions in developing countries and/or in slum areas, certain parts needed to be adapted and considered as such. Therefore some car parks within the area were divided to represent the small dwellings found in slums. This then makes the area chosen a mixture of informal and formal settlements for the field tests. The forms of landscape of the area include small and large buildings, open areas, car parks (slums) and networks.

5.3 Base Image Preparation

Base images of different types and from different sources that meet the requirements of the point cadastre may be adopted for use at different points in time. For example satellite images found available and cheap at the time needed then it must be adopted for use rather than waiting for what is existing in the system. Therefore various kinds of images may be brought on board depending on their status at the time needed. These images may need to be positioned in a way that will best fit together. Therefore this section experiments and assesses various ways of getting the images in shape for point cadastres. This is centred on image acquisition and processing.

5.3.1 Acquisition

Acquiring the Google image requires some special skill including some knowledge in python programming that allow extraction of good workable images using sets of codes at a resolution of the operator's choice. The images used in this research were therefore extracted at 0.5 m resolution with no further processing and referencing required. Extracting the image however takes some time to complete depending on the required resolution. A Quick bird image of 2.4 m resolution, Ikonos image of 4.0 m resolution and a 1m panchromatic image from Ikonos were just downloaded from a source as directed by the provider. However there is the need for processing and that require special software and skill. The Spot image has a 2.5 m resolution and the Quick bird image 2.4 m.

5.3.2 Processing

The Quick bird and Ikonos images were processed using three different software packages and were evaluated based on level of skill required, time needed in the processing and the output visual quality. The images used were pre-processed and corrected for both radiometric and geometric errors. Therefore further processing of the images was mainly on classifications and sharpening. The methods tried in this research to get the images to the desired level are supervised and unsupervised classifications and also image fusion. The detailed flow for processing was as follows:

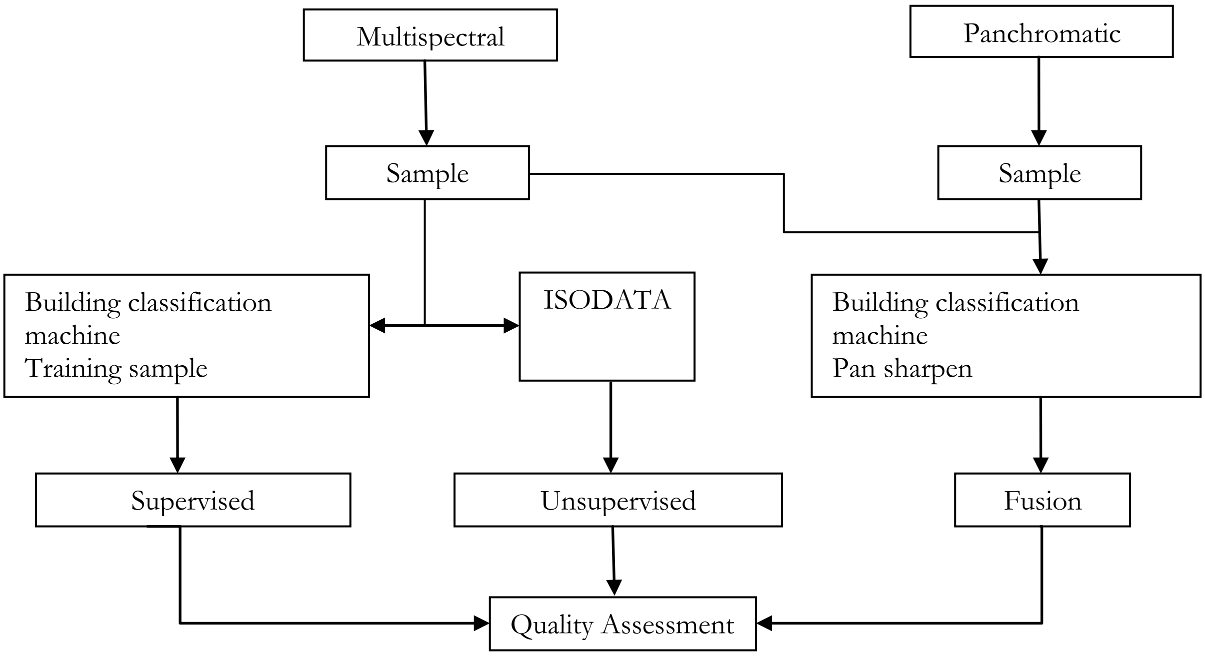

Figure 5-2: Image Processing Flowchart

Before starting the processing, subsets of the images covering the same area were taken using coordinates of the area desired. This then made it possible to assess the image on the same level with little biases.

First, unsupervised classification was undertaken using the Iterative Self Organising Data analysis technique algorithm (ISODATA) which forms cluster of pixels with similar characteristics. This is a very fast and easy method but output do not correspond nicely with the desired information classes.
In the supervised classifications, identification of the classes to be used was first done and this lead to the selection of training sample. As much as possible the training samples were merged leaving eight individual training samples selected in both cases. During the processing, maximum likelihood formula was selected as the parametric rule. Then by selecting the classification function in the menu the classifications were initiated. This process is quite laborious and time consuming as compared to the unsupervised but the desired classes were obtained. As expected, classification of buildings is very difficult and produces bad output visually due to wide range of reflectance associated with each and every building. Therefore a more advanced method is required to obtain images of better visual quality. Below are samples of the output of the processed image and the Google extracted image (figure 5-3).

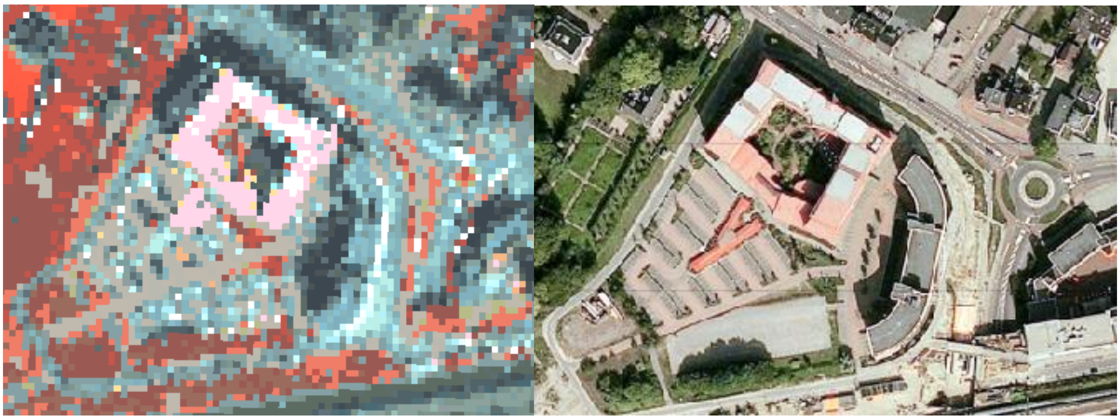

Figure 5-3: Supervised Classified High Resolution and Google Images

Due to the unreliable quality of the outputs, there was the need to seek other alternatives for better results. The technique of image fusion which is also referred to as pan sharpening or resolution merge was tried in this case. This technique involves the combination of multiple images into a composite product. This increases the resolution of a colour image using a higher resolution pan image. In this research a 4 m resolution ikonos multispectral image and a 1m co-georegistered fine spatial resolution panchromatic (black/white) image also from ikonos were used. Typically, three low resolution visible bands – blue, green and red – are the main inputs to produce a high resolution colour image as shown in figure 5-4.

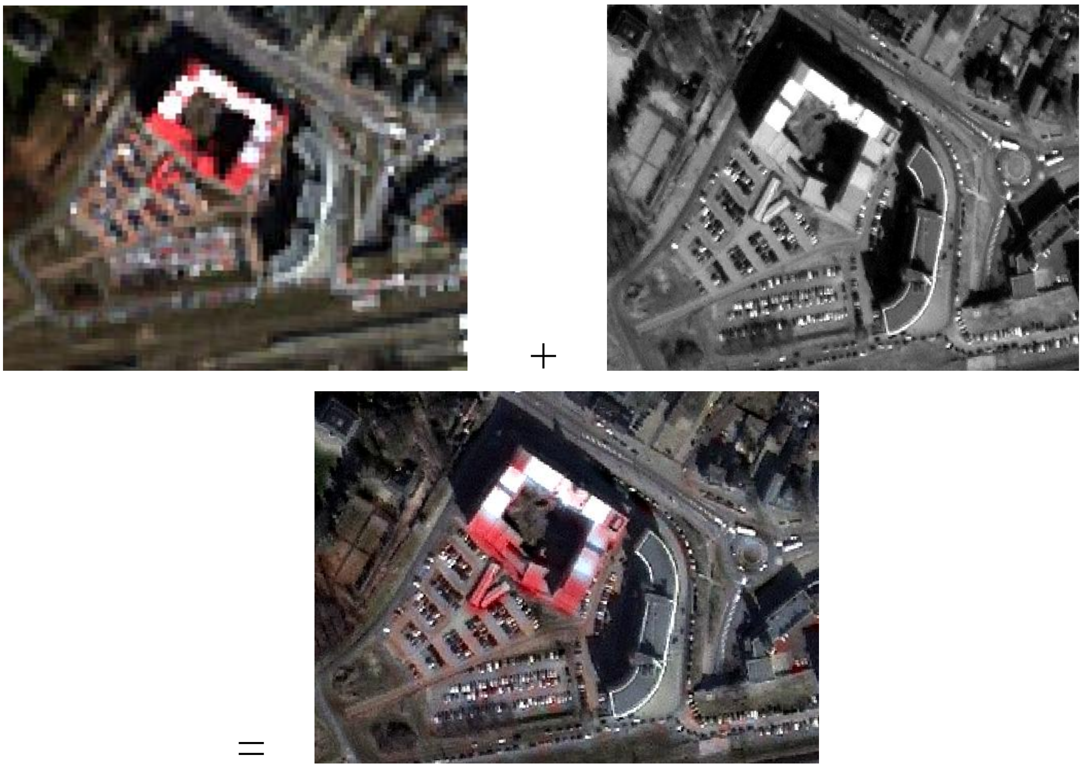

Figure 5-4: Fusion of Multispectral and Panchromatic Images to produce a Pan Sharpened Image

The Google and the pan sharpened images which are visually better are rather very big in size comparatively. Therefore the images were classified unsupervised into a single band and this reduced the storage sizes of the images to almost a third for easy storage and handling.

The images below (figure 5-5) shows a sample of the unsupervised classified pan sharpened and Google images at the same histogram stretch. Even though the pan sharpened image is more visually desirable and can be compared to the Google image, its visual quality after the classification is very much reduced.

Figure 5-5: Unsupervised Classification- Google and Pan Sharpened image

5.3.3 Image Preparation Assessment Results Summary

In the preparation of the images, three different options were considered. Table 5-1, below shows a qualitative comparison of different base images prepared for the point cadastre prototyping in this research. These were assessed in terms of the cost to the images; required skill; ease of processing and ease of increasing coverage area. Inputs for arriving at these assessment results were extracted from the detailed assessment data in appendix 5. Further discussions on final choices are put up in chapter 6.

	Base image		
	Google	Quick bird	Ikonos
Cost	low	high	high
Extraction(downloading) skill required	medium	low	low
Ease of increasing coverage area	high	medium	medium
Ease of data processing	high	medium	medium

Table 5-1: Summary Qualitative Results - Image Preparation

5.4 Storage Device Setup

The geo-databases design setup for the storage, query, and manipulation of the geographic information were carried out with ArcGIS and Quantum GIS. Due to time constraints, a third device, Geomajas could not be tested in this research. It is however introduced with some general assessment.

The initial thematic layers used were the processed satellite images and the point cadastral overlays created out of the initial field survey of some parcels and also control points. Generally, schema diagrams (appendix 2) were used to describe the database design and decisions. The diagrams and the tabular data were prepared with the relationships tested in 'Access' database. Once the schema was working in the geo-database, larger sets of data were loaded into the geo-database. The schema test is an important step settled in the design before populating the geo-database.

5.4.1 Setting up ArcGIS

While using Arc Catalog 10 in ArcGIS raster data were organised in datasets in a raster catalog. The data requiring projection to the local coordinate system were undertaken to ensure conformity among the layers. Feature data were also grouped into their respective feature classes. Where necessary, relationship classes were specified to store information relating to relationship between two feature classes; between a feature class and a non-spatial table; or between two non-spatial tables. Using 'join' and relate tools the tabular data were introduced accordingly. Procedure for introducing more tables and layers are described under maintenance in section 5.7.

5.4.2 Setting up Quantum GIS

Quantum GIS interface and working procedures are quite different from that of ArcGIS. It has fewer direct working tools but possess several plug-ins that provide what it take to at least support viewing, editing and basic querying of the point cadastre system. Issues of feature datasets and classes do no arise here. Data are simply grouped into what appears like ordinary folders.

The initial data made ready for use were first grouped into a single folder. The base images (raster format) were introduced and assigned a projection of Amersfoort/RD_New using the authority id 28992. With all layers rightly projected, the surveyed points in excel format saved as comma delimited (csv) files as required by the software were converted into vector layers and displayed. Through this vector layer and its unique id field all other tabular information were introduced using the 'join attribute' tool.

5.4.3 GeoMajas

Geomajas is free and open source software for web-based applications. This uses cloud based GIS applications for data storage and analysis. Cloud based GIS applications is the future for geospatial infrastructure(Yang, Raskin, Goodchild, & Gahegan, 2010) and point cadastres cannot be left out. This means that fewer resources in terms of computers and IT technicians are required. Unfortunately, the full application and assessment of this alongside ArcGIS and QGIS in this research was not possible due to time constraints. In spite of the constraint its advantage in cost and scalability are highlighted in this research.

5.4.4 Storage Device Assessment Results Summary

Basically, the storage devices were assessed on the ease of use, speed, cost and scalability. These were done in the initial stages of building the databases and during the stage of maintenance (updating, increasing, etc) data in the system. A summary of the results is found in table 5-2 below were deduced from the detailed assessment data in appendix 5.

	Storage Device		
	ArcGIS	Quantum GIS	GeoMajas
Cost	High	free	free
Level of skill required	medium	medium	
General interaction/operational speed	medium	High	
Storage capacity (scalability)	medium	medium	High

Table 5-2: Summary Qualitative Results - Storage Device

5.5 Field Data Collection Processes

According to (Clegg et al., 2006), GPS is an important and integral component in any digital mapping system and the choice currently available is large. They explained that the choice of a particular GPS is determined by the mapping task to be undertaken. (Hill, Moore, & Dumville, 2001; Serr, Windholz, & Weber, 2006) also showed in their research that various low cost GPS receivers produce results desirable for their intended purpose including cadastral mapping when the right techniques are applied. Following these, three different available GPS receivers were used in the prototyping process.

This involves the setting up of the mapping tool itself, the capturing of data in the field, downloading and processing of data acquired. First the device is set up in the right mode with all required specification. The data collection procedure and acceptable data types are all considered within the setup. The data collection process (GPS observations) were done using two handheld GPSs and one high grade GPS mostly in Real Time Kinematic (RTK) mode. Using the Trimble Juno SD handheld real time corrections via SBAS provided by EGNOS were utilised while the Leica 1200 received correction through GSM service. Uncorrected positions were then received in the case of the Garmin 12XL. These techniques applied have the following advantages:

- implementation is relatively simple;
- observational technique is robust, therefore requiring minimal training;
- no base station is required to support rover units (productivity can then be increased at a relatively low cost); and
- no coordination is required between rover units and base units

Leica 1200 is a high grade GPS and know to produce highly accurate coordinates. This type of equipment of that accuracy is very much known among cadastral surveyors. This was therefore necessary to serve as a bench mark for the results from the other GPSs. It has the GSM functionality of receiving corrections real time. Even though it is presumably accurate for cadastral surveying, its accuracy and precision were ascertained using some existing control points.

The Trimble Juno SD handheld GPS receiver was one of two handheld receivers chosen for this research mainly due to fact that it is relatively cheap when considering its positional accuracy claimed by the manufacturer. It is a relatively new tool that provides operating system which makes available all features of a mobile computer including spread sheets, documents, notes, internet and a camera. Garmin GPS 12XL is a rather cheaper handheld GPS of highly sensitive receiver, greyscale display with an electronic compass. Unlike the others this tool was purely chosen because of availability, cost and results in some other researchers' work that exhibits its potential in point cadastres.

These surveying equipment have unique software for data processing and for field data collection. For example Leica 1200 uses Leica Geo Office whereas Trimble Juno SD handheld uses Pathfinder office for processing the data. Also Trimble Juno SD handheld has several field data collection software applications like TerraSync and i-capture. These are data capturing options among others that are also evaluated and assessed using the same set of requirements.

Further description of the GPS survey methodology outlined seeks to document the processes applied. The methodology is divided into the following three categories: pre-field procedures, field procedures, and post-field procedures. The three GPS mapping devices used in the building and maintaining of point cadastre were assessed based on the items outlined in the assessment framework. In summary the assessment borders on cost, ease of use, accuracy and speed.

5.5.1 Pre-fieldwork

As usual a comprehensive planning ahead of any GPS observation mission is quite essential for its efficiency. Therefore obtaining prior assessment of the satellite coverage and rover configurations was given much attention before proceeding to field. The satellite coverage was checked from the internet or the in-built Trimble Quick Plan software that provides satellite visibility plots and reports when the GPS rover is first activated to assess the almanac. The information includes the number of satellites, satellite availability, PDOP, elevation, azimuth, and a sky-plot. The requirements for choosing best time for the survey were:

- availability of a minimum of 4 satellites required to determine a 3-D position, and
- low PDOP values are required for reliable point positioning.

The rovers were configured to specific operational conditions to control the circumstances under which data are collected. To ensure these the rovers were configured to the following parameters to ensure consistencies:

- logging interval which specifies the regularity at which positions should be stored was set at 5 seconds
- elevation mask was set at 10 degrees to eliminate satellites that are very close to the horizon
- maximum PDOP was set 20 to ensure that data are collected only when satellites are in good orientation
- the minimum SNR set at 33 was to ensure that low signal strength that have effect on positional accuracy are eliminated (not possible in Garmin 12XL)

In addition, other parameters included are antenna height was set at 1.00 m on the handhelds but 2.0m was used in the case of the Leica1200; minimum number of positions was pegged at 5; and WGS 84 datum was applied.

A spread sheet for entering attribute data collected in the field was also designed in the Juno SD prior to the field data collection. Key items on the sheet are parcel identification number, address, owner information, land cover, type etc. Alternatively, 'i-capture' which is a personalised designed interface for quick entry of data in the field only is possible to use in the Juno SD. Also in the Leica 1200, a designed sheet was prepared for attribute data entry. A separate sheet of paper was designed for recording data in the case of the Garmin 12XL.

5.5.2 Fieldwork

In surveying fieldwork thorough reconnaissance is considered essential but very minimal reconnaissance was undertaken in this process because of the absence of base stations and therefore identification and testing of control points were not required. However the area to be surveyed was identified and some sketches drawn.

Unlike the Juno SD and Garmin 12XL GPS receivers which are handheld and therefore require no mounting accessories, setting up the leica 1200 with its cables and poles/tripod requires a lot of time and experience. When the devices are powered and switched to the GPS data collection mode the configurations are displaced and checked once again. The measurements are preceded by selecting the file in which the data will be stored. Identification of the point to measure was always a challenge as buildings on the parcel under survey sometimes blocked signals and that the point had to be moved further away from the intended position. The point id which is ideally the parcel id is assigned directly to the point. The spread sheet created or otherwise is then properly filled out with the available data. When necessary photographs were taken and attached to the points in the case of the Juno SD. Other notes including signatures deemed necessary and missing from the spread sheet were also recorded in the notes section of the Juno SD.

5.5.3 Post-Fieldwork

Data collected at the end of each mission was downloaded to the appropriate software and a copy saved to a removable storage facility as a backup. This was very necessary to leave memory space free for the next set of observations. The data collected in the field comes in four files: the geographic data file; the spread sheet file; the extra notes file; and the photography file. Some of the files were in hard copy depending on the mapping device used. Therefore some time was spent in the organization of the data.
By using the SBAS in the Juno and the GSM in the Leica all correction were received and applied at real time. However there was the need to further assess the accuracies and therefore post processing was required. All coordinates were acquired and presented in the local datum – RD_New (Netherland).

As part of the assessment post-processing of the data in the respective software were assessed. Therefore, GPS pathfinder Office was used for the Juno SD and Leica Geo Office applied in the case of the Leica

1200. These then necessitated the inclusion of the base data extracted automatically from the internet using the software. However the DNR Garmin software provides opportunity to download the stored data and undertake some manipulations but not post-processing.

Having just two points of known coordinates, GPS1 and GPS2, more controls were introduced in order to properly assess the mapping devices. The initial processed results from the high grade Leica 1200 GPS turned out very accurate when compared to the known positions and therefore the average coordinates of newly introduced points were adopted for assessing the results of the other equipment. These new positions and that of GPS1 and GPS2 referred to as 'known' coordinates or positions were then compiled into a spread sheet for assessment of their accuracy and precision.

To compare the GPS receiver results, positions measured with all three units were used to determine the Circular Error Probability (CEP). The CEP is a simple measure of accuracy determined by the number of points within a certain distance of a specific position as a percentage of the total number of points. So the CEP means the distance within which half the points would lie closer to the specific position.

5.5.4 Mapping Device Assessment Results Summary

Results of the assessment of the mapping devices are summarised in table 5-3 below. The detailed results in appendix 5 are the basis for the qualitative data below.

	Mapping Device		
	Juno SD	Garmin 12XL	Leica1200
Cost	medium	low	Very high
Level of skill required	medium	low	high
speed	medium	high	medium
mobility	high	high	low
Scalability (all data forms)	high	low	medium

Table 5-3: Summary Qualitative Results - Mapping Device

Table 7 below shows the accuracy levels using CEP of the various devices when being compared to the known positions and also when compared to the average positions obtained from the devices. CEPs are usually for 50% but were also extended for 75%, 90% and 95% of the positions taken in specific modes of application of the device. For example 50% of all data measured with Juno SD fall within 2.450m error of the true position when post processed and 3.448m of the same position when unprocessed. However, the equipment appears to produce positions within a closer radius of its mean position. Unfortunately, only two real SBAS corrected positions were received with the Juno SD and was therefore not included in the assessment. Details from which these results were extracted are presented in Appendix 6.

CEP	Known coordinates			Mean coordinates			
	Trimble Juno SD		Garmin 12XL	Trimble Juno SD		Leica 1200	Garmin 12XL
	post processed	Unproc-essed	Unproc-essed	post processed	Unproc-essed	Realtime corrected	Unprocessed
50%	2.450	3.448	15.114	1.575	2.318	0.192	0.572
75%	3.252	5.118	17.483	3.661	3.828	0.312	0.925
90%	5.073	7.376	18.047	6.215	5.811	0.452	2.123
98%	9.917	37.293	28.899	10.608	10.836	0.678	5.991

Table 5-4: Summary Quantitative Accuracy Results - Mapping Devices

5.6 Creation of Cadastral Overlay

Creation of cadastral overlay may be done through a number of means but digitizing existing maps and the extensive field survey of all cadastral parcels are considered in this research. The overlays basically are presented as dots some of which were later converted into polygons. Conducting field survey dominated in the initial stages in order to serve as a guide to building the database. All overlays that were captured using field survey points are placed about two metres from the door of the building as the top of the buildings are not easily accessible With the database considered ok on-screen digitization of parcels were carried out with the base image serving as the existing map.

Since high resolution satellite imagery was used and the approximate centroids coordinate for the parcels, were taken and are then assigned unique ids. Although, single points are expected to be in the centres, any position within its areas (or volumes) for convenience sake were equally accepted. In this process no contact on ground was made but attribute data prepared earlier were attached to these points.

A very important factor in the cadastral overlay is the unique identification system. Four different kinds of identifications tried in this research. For example, a parcel with a dot of coordinates 257751.482E 471051.809N, that is situate in Enschede, appears on section 01 on base layer number 06 as parcel number 28 and acquired by Jane Peters from Michael Kent will use either of the identifier as follow:

- Geographic coordinate - E 257751.482 471051.809N
- Map-based - 06/01/28
- Name-related - Jane Peters/Michael Kent
- Alphanumeric - Ens_A_0017

These were tested within the various components in other to assess them on their Uniqueness, Permanence, Ease of use, Ease of maintenance and Flexibility

5.6.1 Cadastral Overlay Assessment Results Summary

In the Cadastral overlay compilation, two different options were considered and these were related directly to the base images. The table below shows a qualitative comparison of different base image content and the cadastral overlay compilation method. These were assessed in terms of the accuracy of point to the intended location; speed of compilation; and the usefulness of the derived overlay as a reference for other data layers from different source. Comparatively, as shown in table 5-5 digitising points on a geodetic controlled base image appear tops. However, other requirements are not assessed here and factored in were later influenced the final choice in the design. Though Speed of compilation and framework relates to flexibility and scalability, and like accuracy other requirements are ranked higher in this research. Therefore further discussions on final choices are put up in chapter 6.

			Base Image	
	Method	criteria	uncontrolled	Geodetic controlled
Cadastral overlay compilation	Field Survey	Accuracy	high	high
		Speed of compilation	medium	medium
		Framework	good	good
	Digitisation	Accuracy	medium	good
		Speed of compilation	high	high
		Framework	good	good

Table 5-5: Summary Qualitative Results - Cadastral overlay compilation methods

5.7 Maintenance

Maintenance is a multifaceted process and is expected to be undertaken by several organizations in practical application of point cadastres. This research only concentrates on maintenance involving base layers, cadastral overlays and attributes in the point cadastre.

Therefore base images used in the maintenance process comprised of more recent ones and also of wider coverage. Since satellite images may be acquired from a wide range of sources, blending them in one single system was also tested. The sample began with the Google image but the quick bird and the ikonos images were introduced as well to scale up the system. More data in the form of the point cadastral overlay were introduced as new additions whereas other parcels were either subdivided or consolidated. Alterations regarding incorrect inputs and changed status of a parcels or buildings were also implemented for assessment. One other important aspect that was conducted was the conversion of points into polygons in the point cadastres system. Some buildings earlier represented by points were converted into polygons entirely on screen.

5.7.1 Maintenance Assessment Results Summary

These few alterations and improvements that were mostly done under office conditions were assessed particularly on speed and needed skill in using the applied software. Table 5-6 below shows the results summary of the assessment of the maintenance processes using the GIS software. The detailed assessment results are found in Appendix 5.

		GIS Software		
Process	criteria	ArcGIS	Quantum GIS	GeoMajas
General Editing	Ease of use	medium	medium	
	Speed	medium	medium	
Converting point to polygon	Ease of use	medium	high	
	Speed	medium	medium	
Attribute/ Base layer Updating	Ease of use	medium	medium	

Table 5-6: Summary Qualitative Results - maintenance assessment in diff. GIS software

5.8 Overall Assessment Summary

The assessment of the prototyping resulted in both qualitative and qualitative terms. To simplify these values (Appendix 5) for easy comparison, the assessments results were translated into ordinal scale of High (H) Medium (M) Low (L) based on the requirements they conform to. For example setting up storage device Garmin12XL can be undertaken by anyone who can at least read and therefore and therefore assigned 'high' on the 'ease of use' column. Knowing that, 'ease of use' is ranked number one among the rest of the requirement it places Garmin 12XL ahead of the other devices with either medium or low when it comes to ease of use requirements. Same is done for all other considerations by applying their rating and their corresponding criterion ordinal values.

As shown in table 5-7 the preferred choices are shaded brown and further explanation to the choices are presented in chapter 6. However both digitising and field survey are essential in the case of the cadastral overlay but much more of digitising is encouraged and therefore field survey has lighter grey tone. It must be noted that accept 'cost' for which the scale 'L' is rated best, 'L' is worse in all others requirements.

Requirement			Availability	Assessment requirement					
				Ease of use	Cost	Time/ Speed	Flexibility	Scalability	Accuracy
Component/ phase	Option	*No:*	*1*	*7*	*8*	*9*	*10*	*11*	*12*
Base image Preparation	Google	*2, 3 & 4*	H	M	L	H	M	M	M
	Quickbird		M	M	M	M	L	L	M
	Ikonos		M	M	M	M	L	L	M
Setting up storage device	ArcGIS	*5 & 6*	H	M	H	M	M	M	
	QuantumGIS		H	H	L	H	M	M	
	GeoMajas		H		L			H	
Setting up mapping device	Juno SD	*3*	M	M	M	M	M	H	M
	Leica1200		M	L	H	M	H	M	H
	Garmin12XL		M	H	L	M	L	L	L
Cadastral overlays	Field Survey	*3*	M	M	M	M	M	M	H
	Digitising		H	H	L	H	H	H	M

Table 5-7: Design Component vs. Assessment Requirements

5.9 Conclusion

A test and assessment of the procedure conducted in this prototype revealed results that suggests that all components tried are applicable in point cadastres. They also fit well into each other and therefore possible to apply only available components. However, a quick glance at the assessment results in this chapter revealed that the application of Quantum GIS as GIS device; Juno SD as field data collecting tool and digitisation for creating the points; alphanumeric identifier as link between the points and the tabular data; and Google images as base layer produces the best outcome based on the assessment requirements.

6 DISCUSSIONS

6.1 Introduction

After implementing and assessing the design in the previous chapter, the research is now at the stage of discussing (figure 6-1) the findings which will then lead to the conclusions and recommendations. The main objective of this chapter however, is to discuss processes and results in other chapters especially chapter 5, in order to derive the final design.

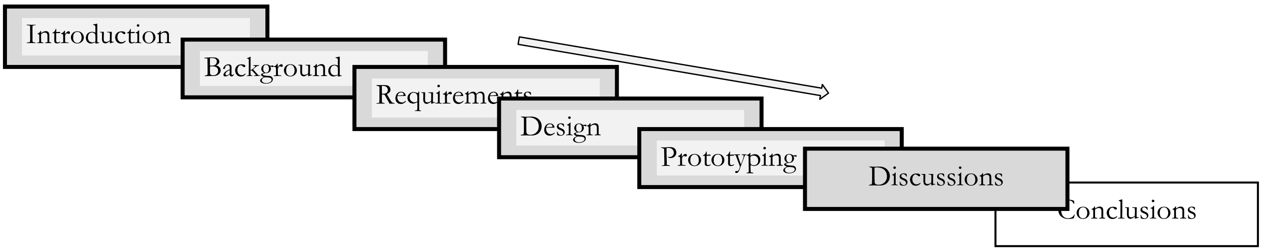

Figure 6-1: Stage Six - Discussions

Data analysis is an iterative process in this research and has been carried out in preceding chapters until now. Chapter 2 analysed data from literature to provide a good understanding of point cadastres. Data obtained from primary sources were also analysed in chapter 3 to establish the requirements for building and maintaining point cadastres. The requirements then led to the designing and prototyping of a process for building point cadastres in chapters 4 and 5 respectively. To recall further details, a reflection on chapters 2 - Background and chapters 3 - Requirements are also presented.

6.2 Reflections - Background

When discussing the conduct of cadastres in developing countries several controversies arise as explained in chapter 2. Attempts at establishing cadastres in many developing countries continue to face challenges in spite of the classic surveying techniques employed. Researchers like (Williamson, 1994) have noted that many of the systems introduced to developing countries by the developed countries are neither appropriate nor can they be afforded. According to (UN HABITAT, 1990), in attempts to prevent problems in future, too much resources are spent on precise surveys rather than simple adjudication to determine who owns each parcel which is sufficient to guarantee title and provide security for landowners. The decision to go for a sophisticated 'precise' cadastre or for simple method sufficient to serve the basic needs of a country remains critical as far as resources are concern. (Molen, 2002) suggests the adoption of a less sophisticated but "appropriate" methodology with less financial and infrastructural backing that must later be improved upon when circumstances permit it.

In consideration of the above, point cadastre which had been used in some countries with some successes in the 1990s (Home & Jackson, 1997) is being considered by some advocates in recent times. When it was used it recorded advantages that by far outweigh its disadvantages. Great potential in point cadastre concept has been identified with the emergence of modern technology and a resurface and implementation of the concept is likely to achieve better results than experienced previously.

6.3 Reflection - Requirements

To design a method for building and maintaining point cadastres, new requirements were sort to serve as guidelines. Though some requirements were found in literature, one could not be sure if they are still relevant today as technology and cadastral needs have changed over the years. Therefore discussions conducted were necessary to contribute to the establishment of requirements relevant for present day point cadastre.

Two main categories namely: components related and assessment related requirements were identified. There are six point cadastre building (components) requirements which were linked to base image, storage device, mapping device and cadastral overlay. The assessment requirement based on which the design was finalised were ranked in order of importance. Therefore, upon responses received from land administration experts the ranking from most to least importance was arrived - Ease of use, Cost, Time/Speed, Flexibility, Scalability and Accuracy.

It was proven during the survey that every requirement selected deserve inclusion. However some respondents suggested other requirements (appendix 1) that attracted the attention of the researcher. The most striking one is the issue of 'legal backing'. This could have been adopted in the research but including such a requirement in the will require more time for the completion of the research. Therefore this is `recommended in a later research.

6.4 Discussion on Design

The point cadastre was designed to reflect the requirements described in chapter 3. However, several options in terms of tools may be adapted to fit in the design. Therefore, deciding on the most appropriate necessitated the assessment of the options using the assessment framework. The application of what is available in terms of tools in the design is the number one on the list of requirements (table 3-2). The options considered in this research were solely what were available to the researcher at the time this research was carried out. These available and applied resources in this research were assessed based on the requirements.

Regarding base image and its preparations Google, Quickbird and ikonos; and also Erdas imagine, Ilwis and Envi Idl processing software were used. Among them Google image was found to best conform to the requirements. Unlike the Quickbird and ikonos images of which more recent ones may obtained easily, the Google image is often out-of-date and can be very frustrating for users. However, it has advantage of being available for all parts of the world and comes at no cost and therefore meets the requirements of availability and cost. Furthermore they may be acquired at varying resolutions which makes it very flexible for users. It may also be used without further processing and thus no further cost is incurred in its preparation. When any form of simple processing is needed for any reason the free open source ilwis software can be applied. Process of acquiring the Google image requires specialised codes to extract but these codes are prepared only once in python programme and therefore the added cost is negligible. The output quality is still high even when classified into a single band in order to sacrifice its true colour for a reduced storage size. Referring to the results in table 5-1, it is also easy to increase the coverage area without much trouble. This is because the image is always available for use. Considering that sub meter accuracy level is not of interest in point cadastre, the image acquired only need to be re-projected unto the local framework without any precise geo-referencing.

Three storage devices – ArcGIS, Quantum GIS and GeoMajas considered in this research belongs to two opposite ends in terms of cost. ArcGIS is rated among the expensive software whereas QGIS and GeoMajas are free and open source. However, their use and data handling are quite different but provide almost the same functionalities relevant in point cadastres. Therefore the cost factor is one very important requirement that cannot be downplayed to determine a good choice. Regarding means of data storage, which could be remotely done (in the 'cloud'), GeoMajas is considered highly scalable but rely much on the internet for its operations. Geomajas has advantage being less dependent on computers and IT technicians for its operation due to the cloud computing capability. However practical application of Geomajas in this research was not possible due to time constraint. However QGIS which is also open source was used to in the prototyping and analysed in this research. It was easy to use especially when only the needed plugins desired for developing point cadastre are activated. Building a database in QGIS is quite easy to do as compared to doing same in ArcGIS. In both QGIS and ArcGIS, data storage is made available on the user's desktop and this gives the user a feeling of having full control on the data. Working off line is also advantageous because users do not have to depend on internet services for constant access to their data. Processes of updating data in the system (maintenance) are no different from the initial building of the database using both software. However, converting points to polygons required more time and experience using ArcGIS. It was noted that query handling and presentations were much easier and processed faster using ArcGIS. Aside the fact that QGIS is open source, it also easy to use, fast and flexible which are key requirements expected of point cadastre tools. It also has a tutorial which was easy to follow by the researcher. Video instructions freely available on the web (YouTube) are also easy to follow and therefore special training in th application of QGIS may be unnecessary.

Concerning mapping devices, Leica 1200 was marked for exclusion from the design at the early stages because of the cost involved and also non availability at all times to the researcher. In spite of its ability to receive GNSS corrections faster and produce accurate positions, it requires much experience or skill to operate. It is also bulky and very inconvenient to transport around. Leica 1200 was best rated for on the accuracy scale which is the least important among all requirements in point cadastres. The other two equipment; Juno SD and Garmin 12XL also assessed are very cheap as compared to the Leica1200. Both are handy and ensure easy movement necessary in both rural and urban cadastres. The Garmin 12XL is relatively very cheap and also available for use. It is also very easy to use and fast in recording positions. However, it lacks the ability to receive real time corrections. The mode of entering attribute is also cumbersome and does not allow the introduction of new fields making it very rigid. Though accuracy is rated least among the requirements, Garmin 12XL's accuracy level is very low and not helpful in slums where properties are clustered together. Positions collected within the 15m accuracy of such areas may not be reliable for planning purposes as well. The Juno SD though a little more expensive than the Garmin12XL, it has more functionalities including the ability to receive real time GNSS correction. It also has additional functions useful in the field data collection processes that make it easy to use and fast in position data collections. Even though the accuracy is not to the level of the Leica 1200, it is by far better than that of Garmin 12XL. It is generally user friendly and allows the inclusion of all attribute fields desired. Memory space can be increased with a microchip and thus meets the scalability requirement. When in the field positions can be viewed directly in Google or other maps. Although, Juno SD is little more costly, it meets the requirements of cost, ease of use, speed, scalability and accuracy. The additional functionalities and also other user friendly capabilities make it preferable choice to the Garmin 12XL in point cadastres.

Cadastral overlay in the system were created by field survey or by digitisation using both controlled and uncontrolled image base layers. Digitisation using a controlled image based layer was found very appropriate for point cadastre because it offers fast and accurate results that fits well in the national reference framework. These qualities also provide opportunities in scalability and flexibility which is not the case when an uncontrolled image is used. Therefore digitising using a controlled image is preferred for easier, faster and less expensive results especially when combined with field surveyed positions which can also serve as a check on the digitised data.

Options considered in the choice of a unique identifier include geographic coordinate based, map-based, name-related and alphanumeric. Alphanumeric was selected even though it does not meet the ease of use requirement. Adjoining parcels' identification could be very different from those in the neighbourhood. However it meets the flexibility requirement as it has few digits that can be understood and adapted by all. It also has the potential to accommodate changes especially in parcel subdivision or consolidation. Its uniqueness and permanence is also an added advantage in point cadastres.

Based on individual results and analysis as well as the design processes carried out, it is concluded that the optimal point cadastre design must comprise of the following components shown in table 6-1 below.

No	Requirement	Function	Component
1	Available Resources	To ensure total minimal initial cost.	
2	National Reference	To avoid the creation of an entirely new system.	
3	Points for Parcels overlay	To serve as a means of identifying parcels for display	Field:-Juno SD Digitisation:- controlled base layer
4	Visualisation	To displayed parcels represented by points pictorially and for digitisation	Google images
5	Unique Parcel Identifier	To serve as a means through which parcels are linked to attributes data	Alphanumeric
6	Display/Query/ Maintenance	To store/display and query system	Quantum GIS

Table 6-1: Final Design Components

6.5 Concluding Remarks

Cost is one of the very important requirements realised in this research. This means that the choice of easy to use, fast and accurate tools should be done whiles monitoring the cost issue closely. Cost is a single requirement that can determine an organization's or country's adaptation or otherwise to the point cadastre. However, the choice of affordable tools to produce a fairly reliable cadastre promotes its use by many other stakeholders.

Flexibility concerns the operator/user's familiarity with the tools and processes in the design. This is therefore subjective and depends on the background and experience of the user. However, tools and equipment proposed are what people are used to in their daily activities. Example Google images, handheld GPS and GIS software are already very commonly used and therefore applying them in a new approach may not be of much problem.

Data processing is necessary to reconstruct geometric conditions to maintain the relationship between features in the database (Fradkin & Doytsher, 2002) even though it takes time and other resources to do so. However the extra time used in the processing is worth spending as unreliable data can impedes the flexibility and later upgrading of points into polygons in the system. The accuracy choice can be simplified to make time gains for the system as well as bring more users on board but fast and acceptable cadastre is the ultimate aim.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

The research is at the final stage, Conclusion and Recommendation (Figure 7-1) and revisits the research objectives and questions along which this research had been carried. The conclusions and recommendations presented in this chapter are drawn by answering the research questions (section 1.5). These conclusions and recommendations have been arrived after the Discussions chapter 6.

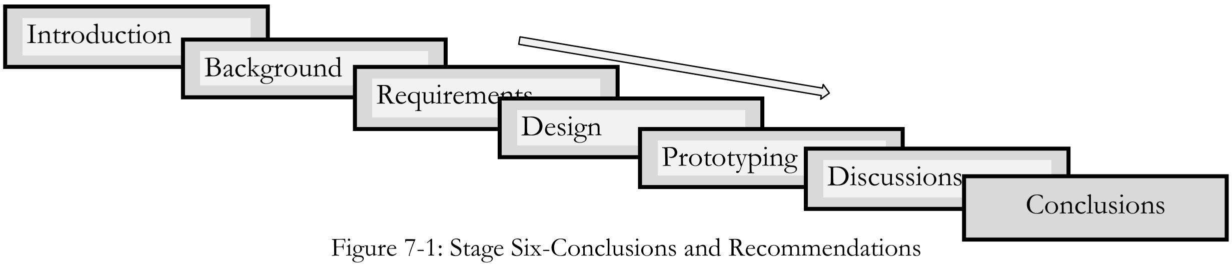

Figure 7-1: Stage Six-Conclusions and Recommendations

7.2 Conclusions

The research objective and questions are presented below with their answers. These questions were formulated such that answers to them would contribute towards fulfilling the objective. These answers were sort from the background review through the assessment of the design (prototyping) results.

7.2.1 Reflections on Objectives

The main objective of this research is to design and assess a modern method of building and maintaining a point cadastre in line with relevant/pragmatic requirements and/or indicators. This involves the identification of relevant/pragmatic requirements for designing and assessing various options of components and processes in a prototype for building and maintaining the system.

7.2.2 Revisiting Research Questions

1.0) What is a point cadastre?

This question is broad was therefore further division into sub questions became necessary. Five sub question related to the main question are presented below with their answers. Answers to these questions are found in chapter 2 of this thesis.

1.1) Which examples of point cadastres exist?

As explained in section 2.4, point cadastres has been used in a number of countries including Thailand, Philippines, Honduras, Denmark, Indonesia, Pakistan and South Africa in the past. For example, in San Pedro Sula (Honduras) 30,000 rural and urban plots were captured within 4 months in a point cadastre.

1.2) Which characteristics do these examples exhibit?

In the examples found points representing parcels are geographically positioned and sometimes marked with stakes. These examples are related to households mostly in the urban areas. The application of photogrammetric (satellite) images and GPSs were common in these examples. They are also exhibited fast and less expensive outputs. None of the examples found included boundary adjudication issues. These characteristics are tabulated in Appendix 4.

1.3) How can different types of point cadastres be classified?

Point cadastres have scarcely been used and refer to by its name without any clear categories or classifications. However point cadastres may be distinguished by the methods applied in developing it. This then puts point cadastres in three classes all or any two of which is possible to use at the same time. These are ‘ground survey based’, ‘desktop based’ and combination as discussed under section 2.5.

1.4) What are the existing approaches to developing point cadastre?

As stated earlier three approaches of building cadastres were identified and presented in section 2.5. These are the ground survey, Desktop and combination approaches. Like the name suggests, ground survey approach require direct field contact to collect data for the building of the point cadastre. Unlike ground survey, desktop approach uses aerial photos to acquire the centroid positions of parcel into the system without going to field. The third which is the combination approach simply combines both point-based and polygon-based parcels into one cadastral system.

1.5) What are the pros and cons of point cadastre?

In section 2.3 the pros and cons of point cadastres were discussed and further details are presented in appendix 4. Point cadastre has advantages of making time and cost savings; serve as a basis for adjudication; and may be easily upgraded into a polygon based. The point cadastre database requires smaller storage size as compared to the polygon based cadastres with little or no topology problems. However it is considered a half-baked solution and therefore lacks the necessary backing by governments for implementation.

2.0) What are relevant and pragmatic requirements for building a point cadastre and what are relevant and pragmatic requirements (indicators) for assessing a point cadastre?

In reference to chapter 2 and 3, twelve relevant requirements for building point cadastres are listed as in sub-section 3.2.3 as follows: 1) as much as possible available resources must be utilised; 2)it must fit into the national reference network; 3)the utilised cadastral overlay must basically be single points; 4)parcels represented by points must also be displayed pictorially; 5)there must be a link between points and attributes data sets; 6)must have means of displaying output and also query system; 7)it must be easy to build and maintain; 8)It must be as very affordable to build and maintain; 9)it must be complete in the shortest possible time; 10)it must be usable by many stakeholders; 11)it must have the ability to increase in coverage; and 12)it must be fairly accurate for planning purposes.

For easy reference and application in the design as well as the prototyping in chapters 4 and 5 , the requirements were grouped into component related and assessment related requirements.

3.0) How can one design a modern method for building and maintaining a point cadastre based on the indicators/ requirements derived in this research?

Considering the requirements, the design of the point cadastre was carried out in parts in Chapter 4. Taking one requirement at a time components were designed to cater for each requirement. Five main phases were applied in the process: 1) acquisition/preparation of base image; 2) setting up of storage device; 3) setting up of mapping device; 4) introduction of overlay & attributes and 5) maintenance. However, each component has a number of options that can meet the requirement in question in each phase. Therefore a test of the various options in a prototype (chapter 5) was necessary for finalising the design. The design was finalised after brief discussions in chapter 6.

4.0) How can the method designed be validated in terms of the indicators/ requirements?

Chapter 5 which deals with prototyping represents a validation of the design. This Components and procedures applied in the prototyping were also assessed based on the requirements - Cost, Ease of use, Flexibility, Accuracy, Scalability and Time/Speed.

7.3 Recommendation

The research was restricted by certain factors that may have contributed to the arrival of better conclusion. However there is still opportunity to draft in more in future researches. To achieve this, the following researches in point cadastres are recommended:

- Given other tools and requirements gathered from people on the ground (users), further research should be carried out to improve the design.
- Further implementation and assessment of the design in a developing country and/or slum area
- Further research quantify the time and monetary savings in building point cadastre compared with polygon based cadastre and also to fully convert point cadastres into polygons based.

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APPENDICES

Appendix 1: Sample Questionnaire and Results

This questionnaire is short (3 questions). It aims to collect and validate design requirements for 'Point Cadastres' from international experts. The survey is being undertaken by researchers at the UNU School for Land Administration Studies at The University of Twente.
'Point cadastres' makes use of single geographic points to represent land parcels. The concept is useful for simple land taxation, land tenure, land use planning, health management applications, and so on. The concept has application in countries where cadastres might be non-existent or extremely limited.
As an expert in the area of land administration, we humbly invite you to participate in the survey. Your survey results will remain confidential. Only aggregated results from all participants will be created and used.
You may forward your comments and/or enquiries to:
Researcher:
Robert Hackman Antwi
Email: antwi21925@itc.nl

Supervisors:
Dr. Rohan Bennett
Email: bennett@itc.nl
Ir. Walter T. de Vries
Email: devries@itc.nl

For you information, the following definitions apply in this research:
•Cost: refers to the costs of technical equipment, human resources, supplies, etc., in producing and maintaining the point cadastre database.
•Ease of use: refers to the level of technical/specialized capacity to build and maintain the point cadastre.
•Flexibility in operations: refers to the capacity of the point cadastre to be used across different agencies by many stakeholders
•Accuracy: refers to spatial accuracy of the points collected (i.e. the closeness of the positions of objects in the point cadastre to the positions on ground).
•Scalability: refers to the ability of the system to be extended for use at regional and national levels (i.e. increasing the types of data collected, spatial coverage, allowing for concurrent users)
•Time/Speed: refers to the time taken to develop the initial implementation of the point cadastre.

Questionnaire
1. Please check as many requirements you deem worthy to consider in the building of point cadastres

☐ Accuracy

☐ Cost

☐ Ease of use

☐ Flexibility

☐ Scalability

☐ Time/Speed

2. Please rank them in order of importance (1st – most important……………… 6th – least important)

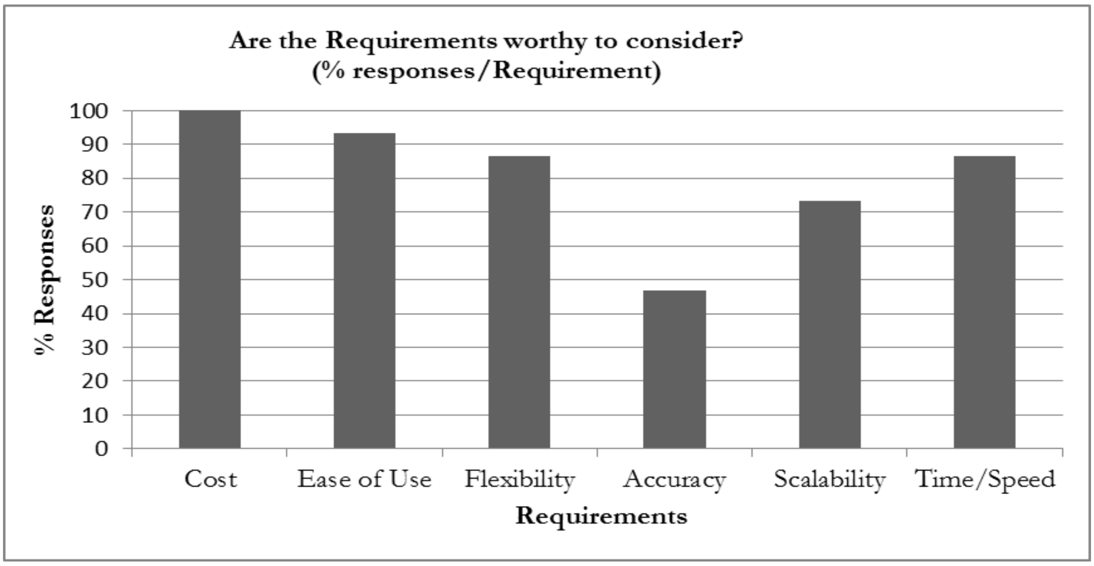
	Cost	Ease of use	Flexibility	Accuracy	Scalability	Time/Speed
1st	○ *	○	○	○	○	○
2nd	●	○	●	○	○	○
3rd	○	○	○	○	○	○
4th	○	○	○	○	○	○
5th	○	○	○	○	○	○
6th	○	○	○	○	○	○

3. Please specify any other requirements you consider important but missing from the list.

Results from Questionnaire

Question 1

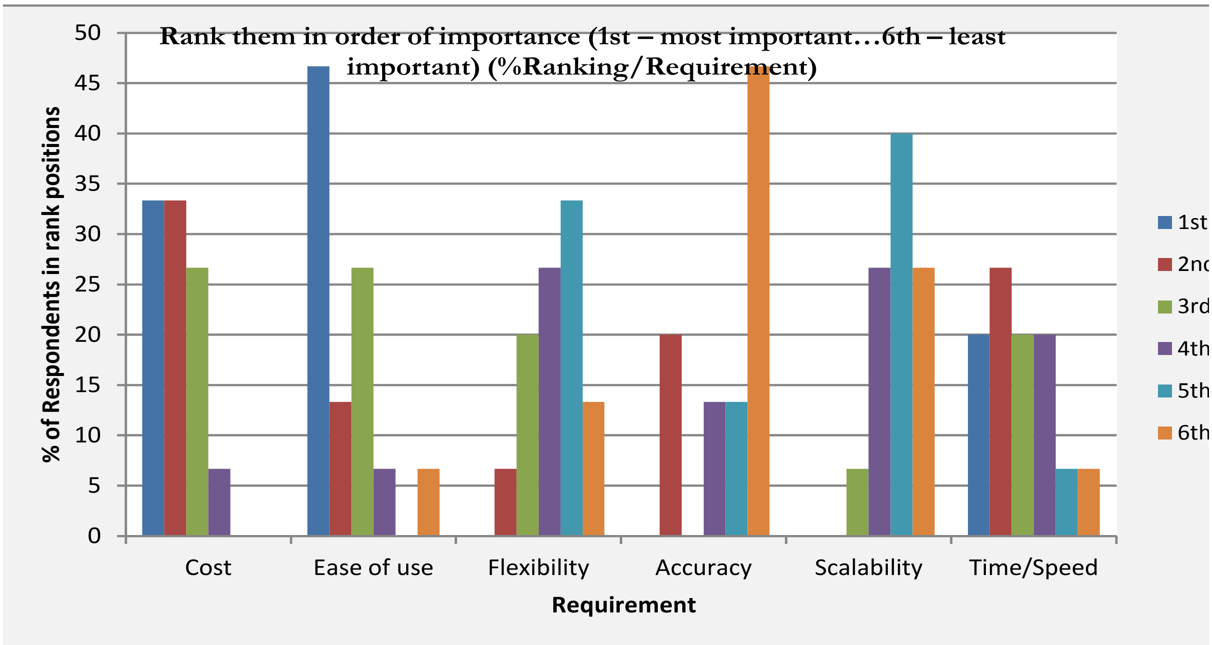
Answer Options	Response Percent	Response Count
Cost	100	15
Ease of Use	93.3	14
Flexibility	86.7	13
Accuracy	46.7	7
Scalability	73.3	11
Time/Speed	86.7	13



Question 2

Please rank them in order of importance (1st - most important................. 6th - least important)

Answer Options	Cost	Ease of use	Flexibility	Accuracy	Scalability	Time/Speed	Response Count
	Percentage scores						
1st	33.3	46.7	0.0	0.0	0.0	20.0	15
2nd	33.3	13.3	6.7	20.0	0.0	26.7	15
3rd	26.7	26.7	20.0	0.0	6.7	20.0	15
4th	6.7	6.7	26.7	13.3	26.7	20.0	15
5th	0.0	0.0	33.3	13.3	40.0	6.7	14
6th	0.0	6.7	13.3	46.7	26.7	6.7	15
						answered question	15
						skipped question	0



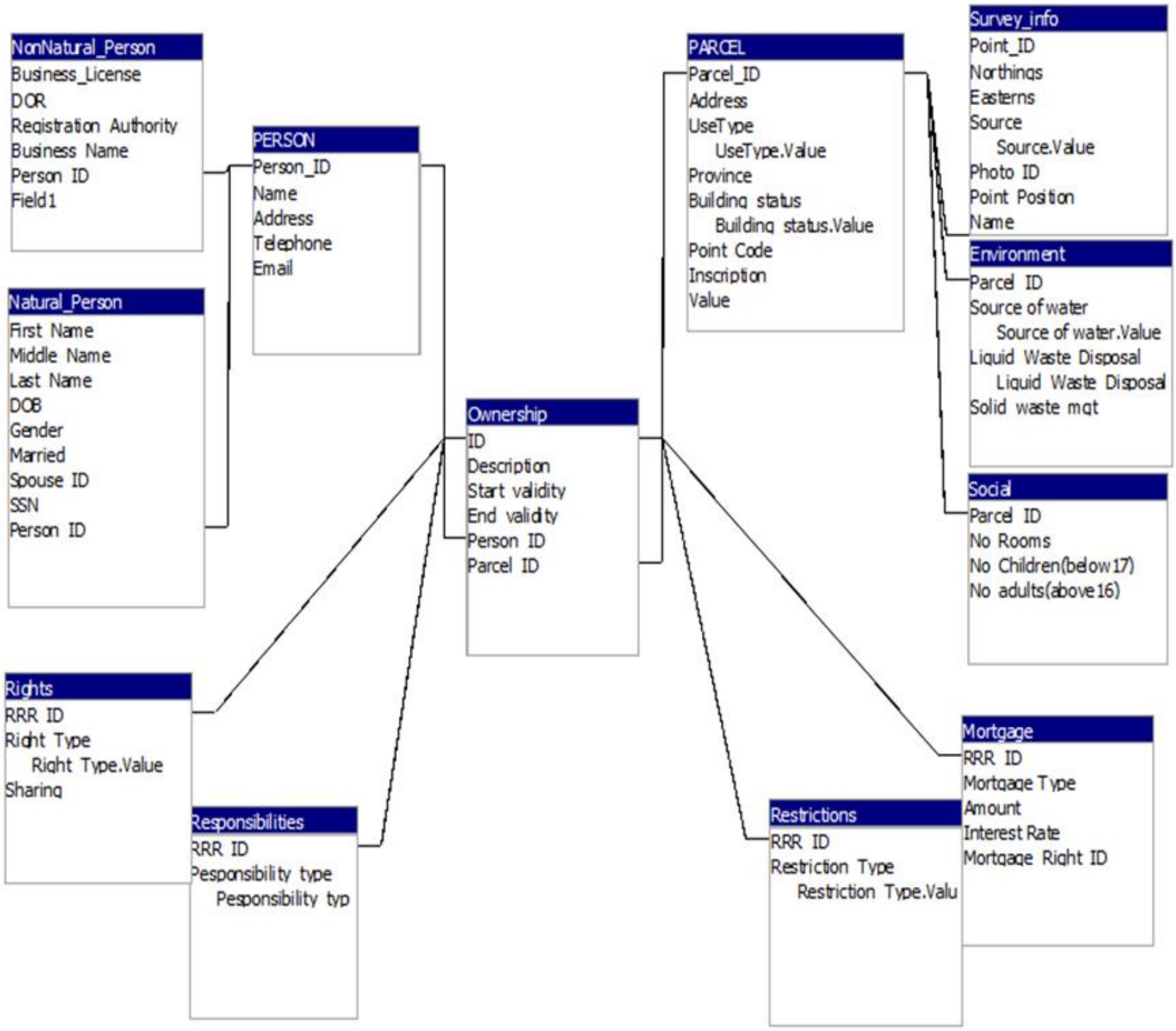
Question 3

Please specify any other requirements you consider important but missing from the list
List of Responses:

- Consider security of poor and vulnerable
- functionality related to legal security
- coordinate system
- security against eviction
- Relevance to objective
- The dots or points can be the basis of a key register, or basis register: a point register. Basis of many and many related registers, like health, electricity etc etc. If scalability is the same as multi-purpose

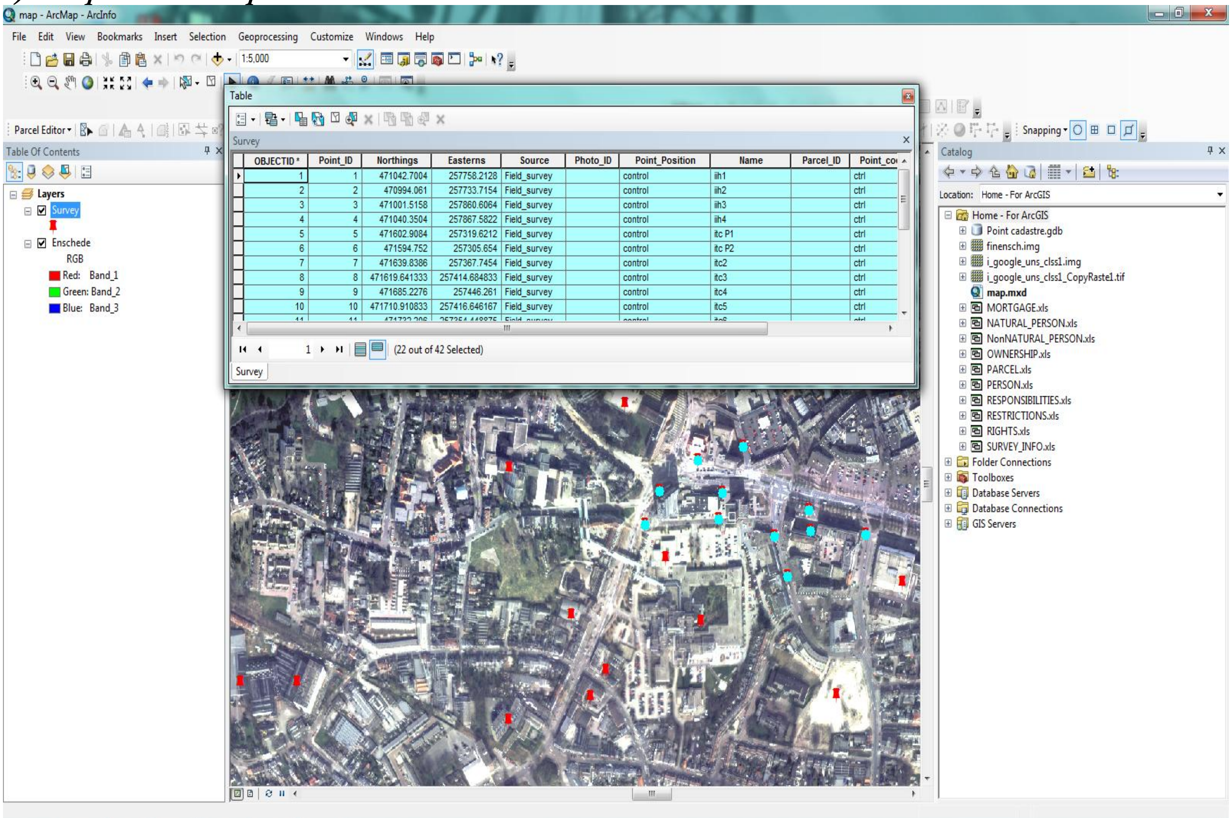
- You have the most important requirements I think. The point cadastre is a good idea in areas where you need to start a cadastral registration system. But it must be quick and cheap to establish in the first instance, and once economic development increases, a complete survey may be considered. I see the relationship between value of the property in relationship to the costs of registration and cadastral identification.
- participation level
- Up to datedness must be an issue not to be forgotten also related to authenticity of the data. Moreover the metadata should be available to the user in a simple form.
- legal definition
- simplicity: the effort en needed skills to operate/use the system
- Please note that costs and time/speed are related. The same is valid for ease of use and flexibility. Scalability is valid for the system as such but also for the field data acquisitions: can it be used for metropolis. Other requirements: - maintainability - link data acquisition and system - access for illiterate people

Appendix 2: Database Design Schema

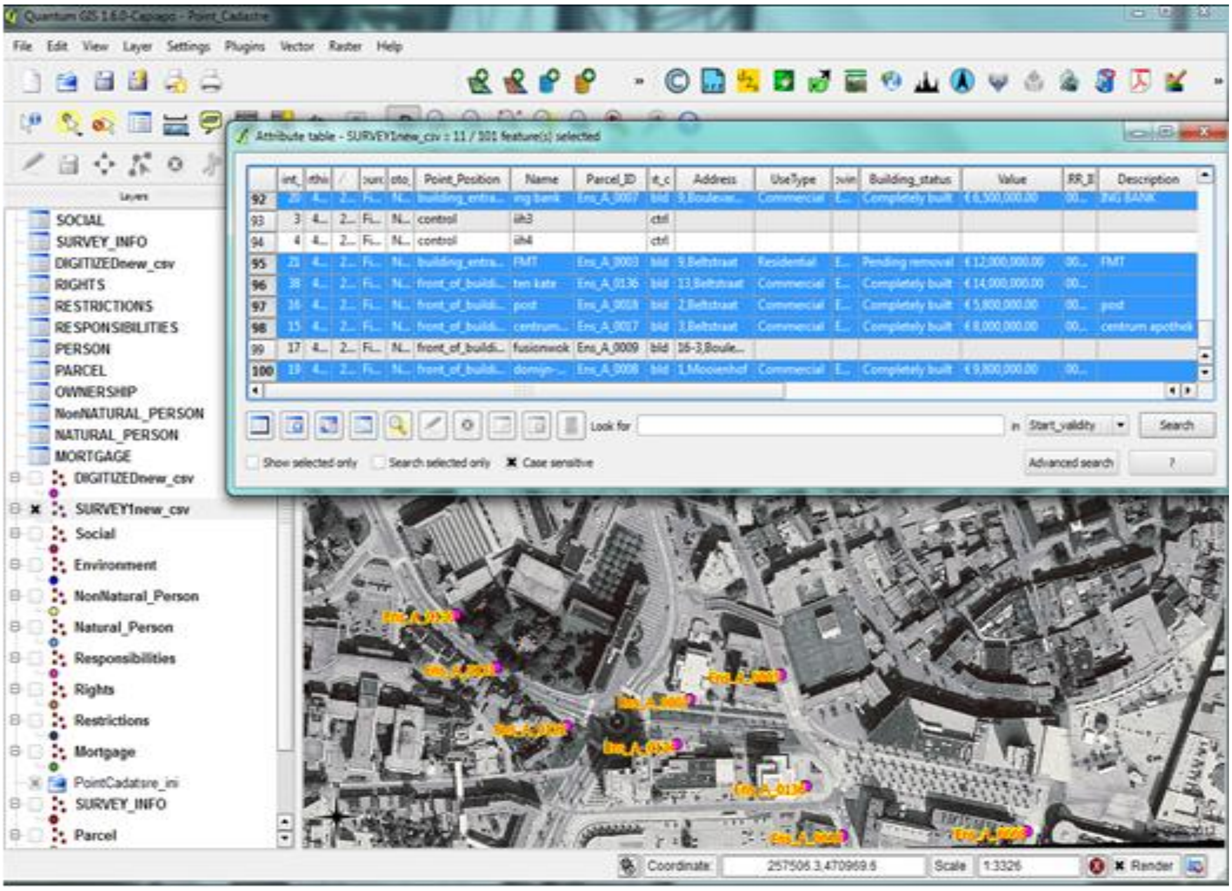


Appendix 3: Screen shots - Point Cadastre Prototype

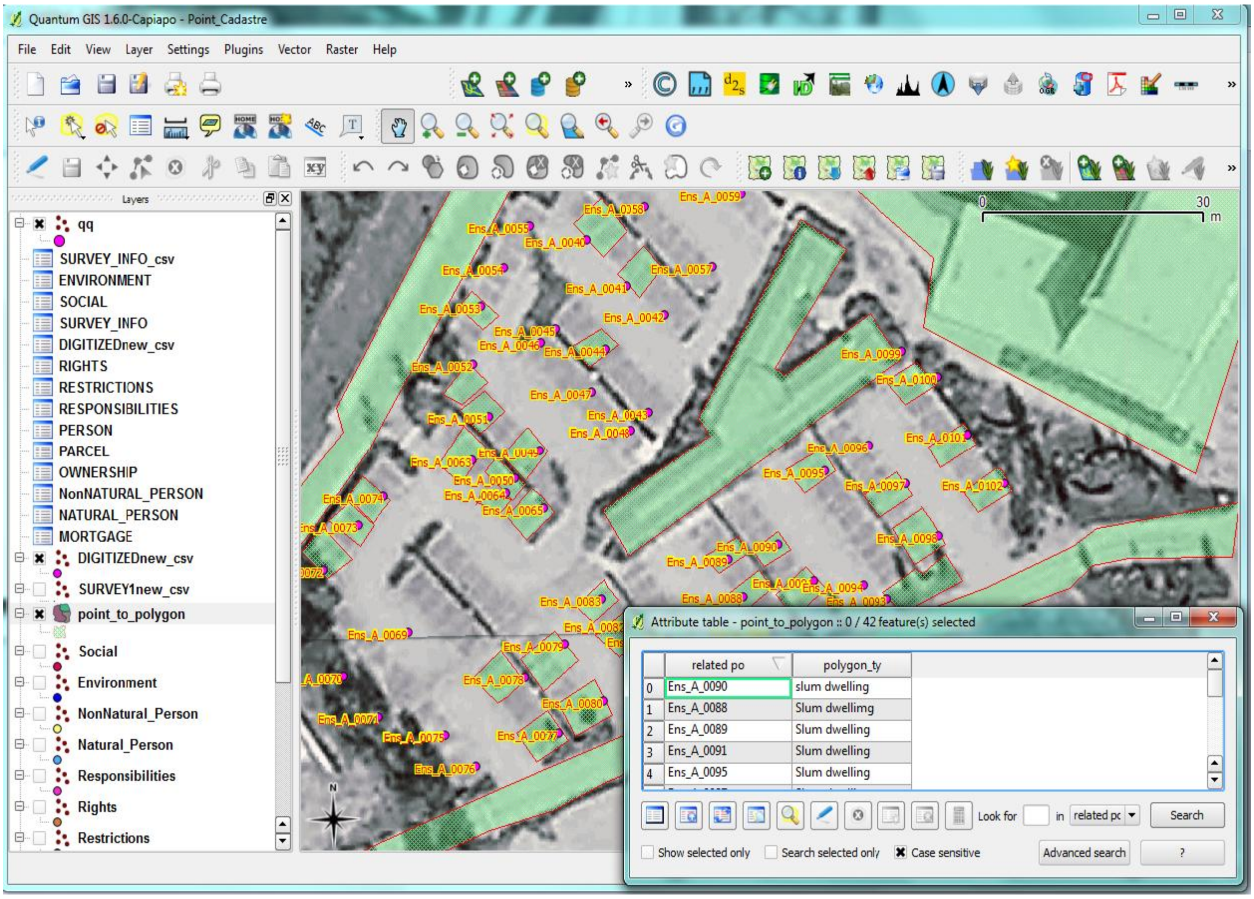
1) Sample in ArcMap



2) Sample in QGIS



3) Point to polygons in QGIS



Appendix 4: Search Strategies and Results

TITLE	AUTHORS	SOURCE	TYPE	SEARCH STRATEGY	YR
social tenure domain model : a pro - poor land tool	Lemmen	Title provided by: christiaan lemmen	Book	Word(s) from the title: social tenure domain model, in database: Library catalogue. Found results: 8	2010
The social tenure domain model: design of a first draft model.	Lemmen, Augustinus, C., Oosterom, P. v., & Molen, P. v. d.	Title provided by: christiaan lemmen	Conference paper	Word(s) from the title: social tenure domain model, in database: Library catalogue. Found results: 8	2007
Our common estate : land rights for informal settlements : community control and the single point cadastre in South Africa	R. Home & J. Jackson	ITC Library Catalogue	Book	Word(s) from the title: cadast*, Word(s) from the title: *point*, in database: Library catalogue. Found results: 4	1997
The application of the social tenure domain model (STDM) to family land in Trinidad and Tobago	Griffith-Charles	ScienceDirect/Elsevier	Journal Paper	5 articles found for: TITLE-ABSTR-KEY(cadast*) and ALL(centroid*) AND LIMIT-TO(cid, "271803,271740","Computers, Environment and Urban Systems,Land Use Policy")	2011
The core cadastral domain model	van Oosterom, P., Lemmen, C., Ingvarsson, T., van der Molen, P., et al.	ScienceDirect/Elsevier	Journal paper	4 articles found for: TITLE(cadast*) and TITLE-ABSTR-KEY(*point*) AND LIMIT-TO(cid, "271803","Computers, Environment and Urban Systems")	2006
Land Registration in Developing Countries – An Introduction	Niels Otto Haldrup	www.amazon.com	PhD Thesis	Books › Professional & Technical › "land registration in developing countries" "land registration in developing countries"	2004
Boundary systems in post- apartheid urban settlements in cape town	Barry M	scopus	Book	ALL("midpoint" AND cadast*)	2007
Urban and Municipal GIS Applications in Developing Countries - the Problems and the Potential	Lauretta Burke, PADCO –GIS Specialist	Google	Conference Paper	PADCO, "point based"	
Options for the Cadastre in the New South Africa:	Dr. Clarissa Fourie	Google	Report	Cadastre, midpoint	1994

Land Administration Standardization with focus on Surveying and Spatial Representations	van Oosterom, et al, 2006	ITC Library Catalogue	Journal Article	Word(s) from the title: Land surveying, Author: Lemmen, in database: Library catalogue. Found results: 2	2011
Participatory Mobile Geographic Information Systems (GIS) for the Regularisation of Customary Land Administration into Statutory Law: A Case of South Africa	Denis Rugege and Morris Mampane Maleka	Google	paper	"single point", "South Africa", gps, survey	2008

Author/yr	**examples of point cadastres**	**Overall outcome**	**classification of point cadastre**	**approaches to developing point cadastre**	**advantages of point cadastre**	**disadvantages of point cadastre**	**criteria for building point cadastre**
Lemmen, 2010			-Point-based -Single point -For rural/urban based LA	Tenure relations collected by handheld GPS in slums	Flexible - can later be developed into polygon-based	Transforming later into topologically structured polygons adds up to cost	Should be possible to integrate with formal LAS
Lemmen et al, 2007			dots on plots PointBasedSpatialUnit		suitable for developing countries, with very little cadastral coverage, post conflict areas and countries with large scale informal settlement	Transforming later into topologically structured polygons adds up to cost	To represent spatial units, parcels, apartments and buildings by dots One right to one or more dot(properties)
van Oosterom, et al, 2006			Single point Point Parcel, Midpoint		Flexible - can later be developed into polygon-based	transformed into topologically structured polygons later	Should be possible to upgrade
Home & Jackson,	PADCO applied	San Pedro Sula	single point,	Use of survey pegs or	Surveyed lots can	Considered half-	The point should

1997	point cadastre in Thailand, Philippines, Honduras & Indonesia	(Honduras) 30,000 rural/urban plot were captured within 4months at 120,000dollars less cost	lots-by-dots, centroid, Mid-point, Point- based	monument 1m from the door of the dwelling. Sketch of the size and shape of parcel can be added.	later be incorporated into the database. Time savings, smaller database, no geometry problems & less expenditure. No boundary adjudication. Can serve as basis for dispute resolution in future. Will require political support. Avoids over-measuring of plot as in fixed boundary survey method	baked system. Aerial survey is much preferred to point cadastre. People are tired of surveys and can false high expectations	lie anywhere in/ just outside the parcel. What the point represents is important and not the accuracy of the point. Must not guarantee boundaries against neighbours. Community cadets' participation with GPS check on orientation, scale & datum is ideal. Should be reconcilable with polygon-based. Must be eventually controlled by local people
Griffith-Charles, 2011				approximate centroid coordinate for the parcel, which may be taken off an index, aerial photograph, Satellite image, or acquired by handheld GPS. The extent of the parcel may also be described textually.	Flexible - can later be developed into polygon-based		Should be possible to upgrade
Niels Otto Haldrup	Denmark	Coordinated	single-point data	Geo-reference	provides an		Apply Block

		addresses are used as key-identifier rather than the land parcel		households by one point and attach range of information.	address that can later be supplemented with boundary information. Boundaries could be surveyed later and possibly link to an address system		strategy. Demarcation of boundary must be left for the neighbours to decide. unique parcel identifier.
Lauretta Burke	Honduras, Indonesia, Pakistan, and Philippines		Lots by Dots	Hardcopy very high resolution satellite imagery or aerial photographs, or using ground-based GPS techniques.	reduced time for input and processing overhead as the point databases are smaller and faster to manage, analyze, update and use cadastral information stored just as with polygon-based no resources spent geometry problems field-built LIS		Must be focussed on geographic (point)position of land parcel, the property identifier and physical characteristics of the land such as: land cover and number of structures. Should be able to absorb additional complimentary data into the database
Dr. Clarissa Fourie, 1994	South Africa		Midpoint, centre-point	Apply block strategy. coordinate (a unique identifier) over a stake in the ground next to a house, and linked to a paper record	Flexible - can later be developed into polygon-based later. Possible to down grade title.		Must fit onto National coordinate referencing system. Must be easy to upgrade Must apply unique

							identification
Denis Rugege and Morris Mampane Maleka , 2008	South Africa		mid-point	Introduction of single point in the centre of a property marked by a stake. Combination of the general boundary method and the midpoint method using a handheld GPS also applies	mid-point coordinate would be obtained using the house as the physical evidence	dwellings are not always located in the middle of their respective boundaries Low accuracy GPS not be appropriate for residential conditions	boundary description must be related to points
van Oosterom et al, 2011			Point-based	coordinates of a single point within its area (or volume)			Recording of positions of a land right is needed not its boundaries

Appendix 5: Assessment Framework (with Results)

	Input & Process	Domain	Option 1		Option 2		Option 3	Variable
Satellite base image	***Image***		*Google*		*Quick bird*		*Ikonos*	Nominal
	Cost/ 25km2	Dollar			600		625	Ratio
	Resolution	[1..10]m	0.5		2.4		4.0	Numeric
	Orthophoto?	[y/n]	y		y		y	Nominal
	Special downloading process?	[y/n]	y		n		n	Nominal
	Technique		python codes		-		-	Nominal
	Level of skill	[H/M/L]	M		L		L	Ordinal
	Image Extracting time	[N]mins	8		3		3	Ratio
	Image size	[N] MB	412					Ratio
Image preparation	***Image processing***							
	Software		N/A	*Erdas Imagine*	*Ilwis*		*Envi-idl*	Nominal
	Cost	Euros	N/A	-	-		0	Ratio
	Level of skill	[H/M/L]	N/A	M	M		M	Ordinal
	Installation size	[N] MB		2942	18		495	
	Processing technique (Classification) Supervised(S) Unsupervised(U) Fused(F)		N/A	S - U -F	S - U -F		S - U -F	
	processing time(average)	[N]mins	N/A	65 - 9 - 13	63 - 8 -19		59 – 6 - 20	Ratio
	Level of skill	[H/M/L]	N/A					Ordinal
	Output quality	[H/M/L]	H	L - L - H	L - L - H		L - L - H	Ordinal
	processed image size	[N] MB						Ratio
Storage/q uery/disp	***GIS software***			*ArcGIS*	*Quantum GIS*		*GeoMajas*	Nominal
	Cost	Euros		>2000	0		0	Ratio
	Installation size	[N] MB		1373	92		59	
	Data Storage			Desktop	desktop		Web based	Nominal

	Building the GDB							
	Time used	[N]mins		54	32			Ratio
	Level of skill	[H/M/L]		M	M			Ordinal
	Geo-referencing /projection							
	Time used	[N]mins		12	10			Ratio
	Level of skill	[H/M/L]		M	M			Ordinal
	Uploading Data into DB							
	Time used	[N]mins		5	7			Ratio
	Level of skill	[H/M/L]		M	M			Ordinal
	Digitizing (20 dots) + initial attrib							
	Time used	[N]mins		28	25			Ratio
	Level of skill	[H/M/L]		L	L			Ordinal
	Maintenance (in…)			*ArcGIS*	*Quantum GIS*		*GeoMajas*	Nominal
	Introducing new points & attrib							
	Time used	[N]mins		16	14			Ratio
	Level of skill [H/M/L]	[H/M/L]		M	M			Ordinal
	Attributes data updating							
	Time used	[N]mins		12	13			Ratio
	Level of skill [H/M/L]	[H/M/L]		M	M			Ordinal
	Converting points to parcel							
	Time used	[N]mins		42	36			Ratio

	Level of skill [H/M/L]	[H/M/L]		M	M			Ordinal
	Updating base layers							
	Time used	[N]mins		15	16			Ratio
	Level of skill [H/M/L]	[H/M/L]		L	L			Ordinal
	Location & attrib data corrections							
	Time used	[N]mins		6	7			Ratio
	Level of skill [H/M/L]	[H/M/L]		L	M			Ordinal
Mapping Device	***Mapping Device***		*Juno SD Handheld*		*Garmin 12XL*		*Leica 1200*	Ordinal
	Unit cost	Euros	800		120		>25,000	Ratio
	Average setting up time	[N]mins	8		6		25	Ratio
	Level of skill	[H/M/L]	M		L		H	Ordinal
	Mobility	[H/M/L]	H		H		L	Ordinal
	positional Accuracy (CEP)	[N]m	2.450		15.114		-	Ratio
	Precision of device(CEP)	[N]m	1.575		0.572		0.192	Ratio
	ease of entering attributes	[H/M/L]	H		L		M	Ordinal
	scalability of attribute mode	[H/M/L]	H		L		M	Ordinal
	Device Software		*GPS Pathfinder Office*		*DNR Garmin*		*Leica Geo Office*	Nominal
	Cost of software	Euros						Ratio
	Level of skill	[H/M/L]	M		L		M	Ordinal
	Processing speed	[H/M/L]	M		M		M	Ratio
	Data capturing approach		*Sporadic*		*Systematic*			Nominal
			J - L - G		J - L - G			
	Cost	[H/M/L]	L – H - L		L – M - L			Ordinal
	Ease of use	[H/M/L]	L – H - L		L – M - L			Ordinal

	Augmentation System		SBAS		Rover-Base station			Nominal
					(J - L – G)			
	Extra initial cost	[H/M/L]	L		M – H - L			Ordinal
	Observation time	[H/M/L]	M		L			Ordinal
	Level of skill	[H/M/L]	M		M			Ordinal
	Post field time required	[H/M/L]	L		M			Ratio
	Data processing		*Post Processing*	*unprocessed*	*Real time*			Nominal
	Downloading time	[H/M/L]	L	L	L			Ordinal
	Time required	[H/M/L]	H	L	L			Ordinal
	Positional accuracy	[H/M/L]	H	L	M			Ordinal
	Level of skill	[H/M/L]	M	L	M			Ordinal
Cadastral Overlay Compilation	**Mode of compilation**		*Field Survey*	*Digitisation*				Nominal
	Base content : Uncontrolled(U) Geodetic controlled(G		U – G	U – G				
	Accuracy	[H/M/L]	H – H	M – H				Ordinal
	Speed of compilation	[H/M/L]	M – L	H – H				Ordinal
	Framework Reliability	[H/M/L]	M – M	L – H				Ordinal
	Parcel identification system			*Geographic coord.*	*Map-based*	*Name-related*	*Alphanumeric*	Nominal
	characteristics							
	Uniqueness	[H/M/L]		H	H	L	H	Ordinal
	Permanence	[H/M/L]		H	L	L	H	Ordinal
	Ease of use	[H/M/L]		L	H	H	L	Ordinal
	Ease of maintenance	[H/M/L]		H	L	L	H	Ordinal
	Flexibility	[H/M/L]		L	H	L	H	Ordinal

Appendix 6: Mapping Device Test Results

AVERAGE CCORDINATES

	Leica_ realtime		**Trimble Juno SD**						**Garmin 12XL**	
PT ID			***Processed***		***Unprocessed***		***SBAS***		***Unprocessed***	
	Easterns	*Northings*	*Easterns*	*Northings*	*Easterns*	*Northings*			*Easterns*	*Northings*
iih1	257758.645	471046.459	257758.213	471042.700	257758.287	471044.392			471051.809	257751.482
iih2	257724.041	470992.450	257733.715	470994.061	257688.265	470981.432	257871.821	471050.025	471002.105	257726.514
iih3	257863.231	471000.930	257860.606	471001.516	257864.221	471003.424	257863.314	471004.233	471008.893	257868.781
iih4	257867.638	471046.912	257867.582	471040.350	257866.241	471041.640			471046.516	257858.960
itc P1	257319.548	471602.647	257319.621	471602.908	257321.392	471605.439			471611.569	257312.547
itc P2	257305.533	471593.431	257305.654	471594.752	257307.216	471596.528			471602.171	257297.612
itc2	257368.500	471639.374	257367.745	471639.839	257369.908	471642.361			471647.206	257360.478
itc3	257413.857	471619.169	257414.685	471619.641	257416.177	471618.118			471627.675	257412.748
itc4	257445.366	471688.527	257446.261	471685.228	257449.279	471684.405			471691.694	257439.817
itc5	257416.460	471707.229	257416.646	471710.911	257415.923	471704.877			471716.534	257408.688
itc6	257352.627	471735.286	257354.449	471732.206	257358.934	471732.113			471739.774	257347.864
itc7	257324.574	471686.440	257326.021	471686.052	257326.143	471688.236			471694.617	257316.289
itc8	257295.434	471634.540	257295.191	471633.246	257296.408	471635.580			471640.165	257287.941
itc9	257332.553	471588.626	257329.610	471588.996	257335.353	471590.954			471596.264	257321.226

PT ID	**Leica_ realtime**		**Trimble Juno SD**				**Garmin 12XL**	
			Processed		***Unprocessed***		***Unprocessed***	
	Easting	*Northing*	*Easting*	*Northing*	*Easting*	*Northing*	*Easting*	*Northing*
iih1	257758.637	471046.461	257757.479	471043.007	257759.276	471046.411	257747.693	471056.014
iih1	257758.711	471046.501	257758.325	471042.051	257756.389	471043.584	257747.492	471055.787

iih1	257758.584	471046.498	257758.748	471043.216	257757.528	471044.995	257748.328	471055.775
iih1	257758.889	471046.387	257757.792	471043.014	257758.911	471043.786	257747.486	471055.768
iih1	257758.404	471046.447	257758.720	471042.214	257759.330	471043.184	257747.413	471055.700
iih2	257724.017	470992.520	257733.881	470994.236	257688.829	470981.804	257723.531	471006.506
iih2	257724.119	470992.625	257732.998	470993.530	257687.280	470980.218	257724.333	471006.205
iih2	257724.017	470992.482	257734.108	470994.821	257689.837	470982.348	257721.876	471006.201
iih2	257724.017	470992.538	257734.325	470992.907	257689.034	470983.002	257721.916	471005.950
iih2	257724.036	470992.083	257733.265	470994.811	257686.346	470979.789	257721.915	471005.661
iih3	257863.242	471000.848	257860.619	471001.645	257864.090	471003.686	257864.706	471012.783
iih3	257863.058	471000.992	257858.624	471000.624	257863.678	471001.995	257865.921	471014.521
iih3	257863.662	471000.851	257859.825	471000.357	257865.934	471002.677	257865.673	471012.362
iih3	257863.144	471000.982	257861.928	471002.954	257864.022	471004.642	257864.722	471013.445
iih3	257863.049	471000.977	257862.036	471001.999	257863.379	471004.119	257864.615	471013.973
iih3							257863.940	471013.262
iih3							257864.100	471012.425
iih3							257866.348	471011.753
iih3							257864.806	471011.516
iih4	257867.552	471046.926	257867.747	471040.016	257865.934	471041.646	257855.454	471050.730
iih4	257867.772	471046.851	257866.668	471043.319	257866.007	471042.261	257855.380	471050.692
iih4	257867.900	471046.886	257869.844	471039.582	257866.123	471040.977	257855.228	471050.577
iih4	257867.449	471046.986	257865.905	471039.322	257866.809	471041.088	257854.958	471050.329
iih4	257867.519	471046.909	257867.747	471039.513	257866.333	471042.228	257854.782	471050.250
itc P1	257320.283	471603.605	257318.363	471602.958	257324.954	471604.860	257308.310	471616.799
itc P1	257320.328	471603.638	257319.638	471602.228	257320.546	471608.654	257308.712	471615.866
itc P1	257320.833	471603.528	257320.154	471603.146	257320.630	471604.288	257308.585	471615.676
itc P1	257320.188	471603.555	257320.059	471603.304	257320.397	471604.728	257308.518	471615.590
itc P1	257321.108	471603.910	257319.892	471602.906	257320.435	471604.664	257308.369	471615.569
itc P1							257308.581	471615.564

itc P1							257308.831	471615.392
itc P1							257309.286	471615.280
itc P1							257309.354	471615.049
itc P1							257308.921	471614.908
itc P2	257306.354	471594.444	257305.867	471594.347	257306.153	471594.186	257293.764	471606.515
itc P2	257306.319	471594.323	257306.412	471596.691	257305.315	471592.604	257293.741	471606.477
itc P2	257306.429	471594.358	257305.393	471593.962	257308.320	471597.313	257293.766	471606.403
itc P2	257306.221	471594.405	257305.419	471593.725	257308.320	471597.313	257293.801	471606.115
itc P2	257307.340	471594.623	257305.179	471595.035	257307.971	471601.222	257293.772	471606.095
itc P2							257293.983	471605.839
itc P2							257293.854	471605.752
itc2	257368.383	471639.715	257369.676	471640.582	257360.939	471639.247	257356.853	471651.537
itc2	257369.203	471639.329	257370.806	471641.182	257370.470	471640.112	257356.682	471651.514
itc2	257368.759	471639.207	257369.348	471640.354	257370.470	471640.112	257356.831	471651.498
itc2	257368.087	471639.113	257360.359	471638.565	257373.778	471646.168	257356.774	471651.497
itc2	257368.068	471639.507	257368.538	471638.510	257373.885	471646.166	257356.722	471650.955
itc2							257356.141	471650.803
itc2							257356.745	471650.639
itc3	257413.902	471619.124	257411.109	471617.497	257417.973	471612.547	257404.990	471633.586
itc3	257413.935	471619.315	257411.106	471617.588	257419.132	471618.785	257429.195	471632.042
itc3	257413.703	471619.097	257410.817	471617.317	257416.629	471619.106	257404.909	471631.690
itc3	257413.889	471619.109	257417.410	471621.862	257415.826	471619.461	257407.297	471631.389
itc3	257413.857	471619.198	257420.361	471625.579	257413.519	471619.163	257403.514	471630.701
itc3			257417.306	471618.005	257413.985	471619.648	257403.785	471630.641
itc4	257445.219	471688.418	257442.583	471684.590	257459.879	471677.682	257434.894	471696.349
itc4	257445.192	471688.548	257441.771	471684.413	257446.991	471693.364	257434.679	471696.186
itc4	257445.198	471688.264	257442.019	471684.927	257446.429	471682.521	257439.046	471696.099
itc4	257445.331	471688.448	257448.906	471691.125	257446.999	471683.747	257434.121	471695.494

itc4	257445.889	471688.958	257456.026	471681.083	257446.095	471684.711	257436.704	471695.211
itc4							257436.661	471694.828
itc5	257416.645	471707.132	257416.501	471704.016	257416.687	471708.691	257404.560	471721.494
itc5	257416.364	471707.098	257417.740	471704.877	257417.212	471707.435	257405.038	471720.822
itc5	257416.437	471707.348	257415.998	471717.092	257416.890	471706.583	257405.269	471720.080
itc5	257416.434	471707.116	257415.122	471715.975	257416.878	471706.337	257404.893	471719.937
itc5	257416.328	471707.326	257415.949	471713.714	257413.575	471699.326	257404.739	471720.887
itc5	257416.549	471707.351	257418.567	471709.791	257414.293	471700.888	257404.873	471719.805
itc5							257404.846	471720.711
itc6	257352.689	471735.413	257354.576	471728.795	257354.951	471735.764	257344.516	471744.114
itc6	257352.534	471735.441	257355.745	471728.813	257358.665	471732.733	257344.357	471744.064
itc6	257352.523	471735.532	257355.965	471729.088	257360.211	471731.843	257344.165	471743.930
itc6	257352.775	471735.139	257356.247	471728.814	257360.703	471731.304	257344.059	471743.778
itc6	257352.351	471735.220	257356.141	471728.960	257354.294	471735.611	257343.914	471743.626
itc6	257352.668	471735.348	257352.865	471735.076	257355.096	471735.373	257343.790	471743.502
itc6	257352.955	471735.009	257352.317	471734.986	257367.721	471724.333	257343.649	471743.406
itc6	257352.523	471735.182	257351.735	471743.116	257359.834	471729.942		
itc7	257324.846	471686.157	257342.158	471683.982	257321.457	471698.007	257312.665	471699.684
itc7	257324.596	471686.253	257318.117	471684.543	257327.258	471686.261	257312.339	471699.378
itc7	257324.655	471686.345	257321.293	471687.261	257327.751	471685.811	257312.059	471699.065
itc7	257324.355	471686.564	257325.819	471685.332	257328.422	471685.777	257311.806	471698.854
itc7	257324.554	471686.560	257326.188	471685.521	257327.990	471685.989	257311.741	471698.667
itc7	257324.398	471686.264	257326.010	471685.861	257332.749	471687.737	257314.321	471696.052
itc7	257324.968	471686.796	257325.662	471686.806	257320.500	471687.191		
itc7	257324.035	471686.521	257322.924	471689.106	257323.014	471689.115		
itc7	257324.755	471686.504						
itc8	257295.562	471634.682	257294.892	471634.303	257296.211	471637.885	257285.285	471645.196
itc8	257295.258	471634.540	257296.674	471632.717	257296.579	471635.793	257283.773	471643.866

itc8	257295.495	471634.852	257294.035	471633.280	257297.230	471636.073	257283.602	471643.826
itc8	257295.625	471634.352	257294.990	471633.240	257297.316	471637.351	257284.199	471643.791
itc8	257295.348	471634.078	257295.235	471633.111	257295.485	471635.144	257283.594	471644.666
itc8	257295.314	471634.734	257295.317	471632.825	257295.627	471631.235	257284.391	471643.646
itc9	257332.467	471588.752	257329.452	471589.945	257333.056	471589.628	257304.424	471577.842
itc9	257332.433	471588.324	257328.966	471590.073	257340.217	471592.878	257303.502	471577.823
itc9	257332.605	471588.993					257304.642	471577.819
itc9	257332.924	471588.563					257304.850	471577.738
itc9	257332.338	471588.497					257304.710	471577.596

calculation of CEP

calc. from		juno_ pro	juno_unproc	garmin	leica
	50%	1.575	2.318	0.572	0.192
	75%	3.661	3.828	0.925	0.312
	90%	6.215	5.811	2.123	0.452
Mean	98%	10.608	10.836	5.991	0.678
	50%	2.450	3.448	15.114	
	75%	3.252	5.118	17.483	
	95%	5.073	7.376	18.047	
Known	98%	9.917	37.293	28.899	

Appendix 7: Mapping Devices– Leica1200, Garmin 12XL and Trimble Juno SD GPS Receivers