# University of Nairobi

## School of Engineering

## Integrating Building Plans into the Existing Cadastral System

Case Study Lavington, Nairobi


**BY**

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## Declaration

I, Kamau Salome Saru, hereby declare that this project is my original work. To the best of my knowledge, the work presented here has not been presented for a degree in any other Institution of Higher Learning.

Signature…………………………………. Date……………………

Kamau Salome Saru.

This project has been submitted for examination with my approval as university supervisor.

Signature…………………………………… Date……………………………

Dr. D.N. Siriba

## Dedication

I dedicate this project to my family and friends for the moral and material support throughout my life and for their great investment in my education.

May the Almighty Lord bless them abundantly.

## Acknowledgement

I express immense gratitude to my project supervisor **Dr. D.N. Siriba** of the Department of Geospatial and Space Technology, University of Nairobi for his invaluable advice, guidance, and commitment.

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To my friends and classmates I wish to express my appreciation for their invaluable and immeasurable encouragement and support that enabled the success of this project.

Above all, I am most grateful to the Lord Almighty for the opportunity and strength to work on this project.

**Abstract**

The National Land Policy was developed with new land laws. Among them is the Land Act 2012 and the Land Registration Act (LRA) 2012 that contains provisions on improving land and property management in the country. The LRA, 2012 made it mandatory for buildings to be geo-referenced so as to be registered making the Sectional Properties Act, 1987 the only legislation to use in the sale of buildings. In the past most developers opted for registering an Architect's plan of the building on which the units (flat or maisonettes) were serially numbered, under the Registration of Documents Act, (RDA), Cap 285 as it was a quicker and way of transacting building units sales compared to the SPA route. These buildings have to be *resurveyed to produce the registration documents* as *required* under SPA.

The survey methods used in SPA are laborious and time consuming; measuring building unit dimensions using line tapes. This project was aimed at developing a method that would ease the laborious survey methods used in SPA. Geo-technologies; Remote Sensing and GIS were used to aid the survey process. It used Remote Sensing and GIS in place of the conventional linen measuring method used in such surveys. Geo-referencing was done using orthophotographs and the building units integrated into the existing 2D cadastral system. The building unit dimensions were obtained from the geo-referenced as-built building plans. Data storage, manipulation and visualization were accomplished using GIS. Sectional plans required for registration under the LRA were then produced.

The study area was Lavington with the focus being on five apartment buildings. 3D spatial technology was used to store, manage and visualize above the line interests in land. In a country where cadastral information is still held as 2D analog records, such a solution represents a significant evolution of the land administration system and provides a foundation for a spatially enabled government and society. The study provided a means of integrating disparate sources of information; land and buildings, that can be used to provide improved analytical capabilities for managing land and property and solving urban related problems.

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## LIST OF ACRONYMS AND DEFINITIONS

**SPA**: Sectional Properties Act, 1987.

**RDA**: Registration of Documents Act.

**RTA**: Registered Titles Act, Cap 281.

**RLA**: Registered Land Act, Cap 300.

**LRA**: Land Registration Act, 2012.

**DSM**: Digital Surface Model.

**CityGML** : City Geography Markup Language.

**As-built building plans**: Final set of drawings produced at the completion of a construction project by architects. They include all the changes that have been made to the original construction drawings, including notes and modifications.

**Building footprints**: Outline of the total area of a lot or site that is surrounded by the exterior walls of a building or portion of a building exclusive of courtyards. In the absence of surrounding exterior walls, the building footprint shall be the area under the horizontal projection of the roof.

**Certificate**: A document given to the owner of a property instead of a title deed. This only happens in apartments and town houses where several units share one title deed because they are built in one piece of land.

**Geo-referencing**: Defining the location of an object in physical space aligning it to a known coordinate system. "Referencing of an object using a specific location either on, above or below the earth's surface", (LRA 2012).

**Lease**: A legal document in which the owner of a property transfers the right to use and occupy his property to another for a specified duration, purpose and for a payment.

**Sublease:** This is created when the head lessee transfers his interest (whole or part) in the property to another tenant for a duration which is normally shorter than period of the head lease. This is normally executed upon consent retained from the lesser (Landlord).

# CHAPTER 1: INTRODUCTION

## 1.1 Background

The current trend in the development of residential houses in major urban areas has been to move from individual units like bungalows and maisonettes to flats and apartments. The latter are now coming up even in areas that had been zoned for low-density residential areas like Kileleshwa and Lavington estates in Nairobi. This is due to the rapidly escalating value of land and the ever-rising cost of building materials that make the cost of housing far beyond the reach of the majority in urban population.

The provisions of title documents for apartments or flats in Kenya are found in the Sectional Properties Act, (SPA) 1987 whose aim is to " *provide for the subdivision of buildings into units being owned by individual proprietors and common property to be owned by the proprietors of the units as tenants-in common, and to provide for the use and management of the units and common property and for connected purposes"*, (Government of Kenya, 1987).

In the past when a developer wished to sell individual flats or maisonettes (with common areas), the developer could apply for registration of an Architect's plan of the building on which the units (flats or maisonettes) were serially numbered, under the Registration of Documents Act Cap 285 (RDA). The apartments would be registered as sub-leases under RDA and the owner of the building unit would be given a certificate.

In the Land Registration Act 2012 (LRA), the Registrar is required to register long-term leases over apartments, flats, maisonettes, townhouses or offices where the property comprised is *properly geo-referenced* and approved by the statutory body responsible for the survey of land.

On the transition of existing title documents, Section 105 of the LRA 2012, states that "the *existing certificate of titles under the RLA, shall be considered as a certificate of title or lease issued under the LRA, provided that the Registrar may at any time prepare a register, in the prescribed form and issue to the proprietor a certificate of lease, as the case may be in the prescribed form*", (Government of Kenya, 2012).

Section 54, (sub-section 4) prescribes the land register for purposes of the Sectional Properties Act to be that prescribed in Section 7 (c) which shall contain geo-referenced plans.

Sub-section (5) states that " *the Registrar shall register long-term leases and issue certificates of lease over apartments, flats, maisonettes, townhouses or offices having the effect of conferring ownership, if the property comprised is properly geo-referenced and approved by the statutory body responsible for the survey of land*".

Building sub-leases under Registration of Titles Act, RTA will have to be converted to LRA. With LRA, making it mandatory for buildings to be geo-referenced so as to be registered, SPA, 1987 remains the only legislation to follow in transactions involving buildings. Buildings whose plans have previously been registered under RDA will have to be resurveyed as per the SPA for the leases to be issued. The regulations under LRA are at the moment being prepared.

Survey procedures in SPA involve fixed boundary requirements. The plans used for registration are Sectional Plan consisting of a Site and Building Location Plan and a Floor Plan. The Floor Plan shows the boundaries of each unit to which the Section Plan relates. Unless stipulated otherwise, the boundaries of each unit are the undecorated inner surfaces of the surrounding walls, the undecorated upper surface of the floor and the undecorated surface of the ceiling. A wall includes windows or doors unless stated otherwise. In the survey of the Floor Plan, all unit dimensions are measured to the undecorated interior surfaces at floor level. A linen tape *may* be used for measurement and the related architectural plan may also be used as a guide during measurement of unit dimensions. Wall and ceiling dimensions are *approximate* and do not include surface finish. For consistency, dimension measurements are made to 0.01m and floor areas calculated in square meters.

This study aims at developing a procedure that can facilitate the conversion process of building sub-leases under the RLA and RTA to the LRA 2012. It explores the possibility of using geo-technologies to supplement the conventional survey methods normally used. This is done by the construction of a hybrid 3D cadastral system comprising of a geo-database of the existing 2D land parcel data and 3D representation of objects, in this case the buildings.

As-built architectural building plans were geo-referenced using orthophotographs before their inclusion into the geo-database. Unlike the conventional practice during topographical and topo-cadastral mapping where the building roofs normally suffice for geo-referencing, footprints were used to geo-reference the buildings to achieve acceptable accuracy.

This study uses geospatial technologies of Remote Sensing for geo-referencing and Geographic Information Systems, (GIS) to produce the geo-database mentioned earlier. It involves a large number of disciplines including; surveying, mapping and cartography, photogrammetry and remote sensing among others.

Remote sensing is the science and art of obtaining useful information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation. Remote sensing was used in geo-referencing of buildings.

Satellite images are relatively cheaper and easier to obtain than aerial photographs but their resolution is sufficient for base mapping and not for modeling small details of a region, in this case buildings. The resolution makes it difficult to extract the buildings perfectly, leading to complicated corrections thereafter. Aerial photography was hence used due to its high accuracy compared to other remote sensing image sources. Approved building plans were geo-referenced with the help of aerial photographs and integrated into the existing 2D cadastral system.

Geographic Information System (GIS) is a computer-based tool for mapping and analyzing things and events that happen on earth. It integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps. GIS was used in storing, managing, mapping and visualization of the inventories of land parcels and buildings.

### 1.2 Problem Statement

One of the basic requirements of the Sectional Properties Act is that floor areas of flats/maisonettes be accurately surveyed. Conventional survey methods currently used in SPA are tedious, expensive and difficult to apply indoors for the purpose of floor areas, and with emerging geo-technologies offering more efficient ways of solving these problems it is appropriate that they are embraced and fully utilized.

While Survey of Kenya employs some of them, there is still lack of information on how much these technologies can do and hence their underutilization. These technologies offer more accurate, effective and efficient ways of survey required to fulfill the requirements stipulated under LRA, 2012 for SPA surveys.

It was on the need to create an easier process of undertaking SPA surveys for building units which can save a lot of time while provide better accuracies that this project was undertaken.

### 1.3 Objectives

The main objective of this project is to demonstrate the integration of building plans into the existing cadastral system towards developing a procedure to aid the survey process of building units in SPA.

The specific objectives include;

i). Extraction of building footprints from aerial imagery.

ii). Geo-referencing of architectural building plans and overlay with parcel boundaries.

iii). 3-D building modelling.

iv). Creation of a sectional plan production workflow.

### 1.4 Justification

The survey methods used in the SPA survey of buildings is laborious, time consuming and expensive. The resulting unit measurements are obtained by summing individual room measurements. It is time consuming taking the individual room measurements then adding them to get the unit dimensions. The resulting dimensional unit accuracy will also be low. There is thus need to use more effective and accurate survey methods.

Geo-technologies offer the solution to this in an efficient and also cost effective way compared to conventional survey methods. Since these technologies are in use at the Ministry of Lands, implementation of such a system will be relatively cheap and quick.

Other benefits include;

i). Less laborious process of geo-referencing maps and buildings.

ii). Higher positional and areal accuracy for units compared to what is achieved when using linen tapes.

iii). Offer an efficient land record management system.

### 1.5 Scope

The scope of this project is to integrate buildings into the existing cadastral system and produce sectional plans for registration of building units under LRA 2012 in Lavington area, Nairobi County. This study is limited to a part of Masiwa sub location Lavington, focusing on five apartment buildings.

Lavington is a middle to high income residential suburb located 7km North West of Nairobi's City Centre. It lies between Westlands and Kilimani, and neighbors Kileleshwa to the East. Its feeder roads link to James Gichuru Road. The map below shows the area.

The area selected was due to the abundance of flats sold under RDA and the availability of up-to-date fixed boundary cadastral maps. Figure 1 shows the area studied.

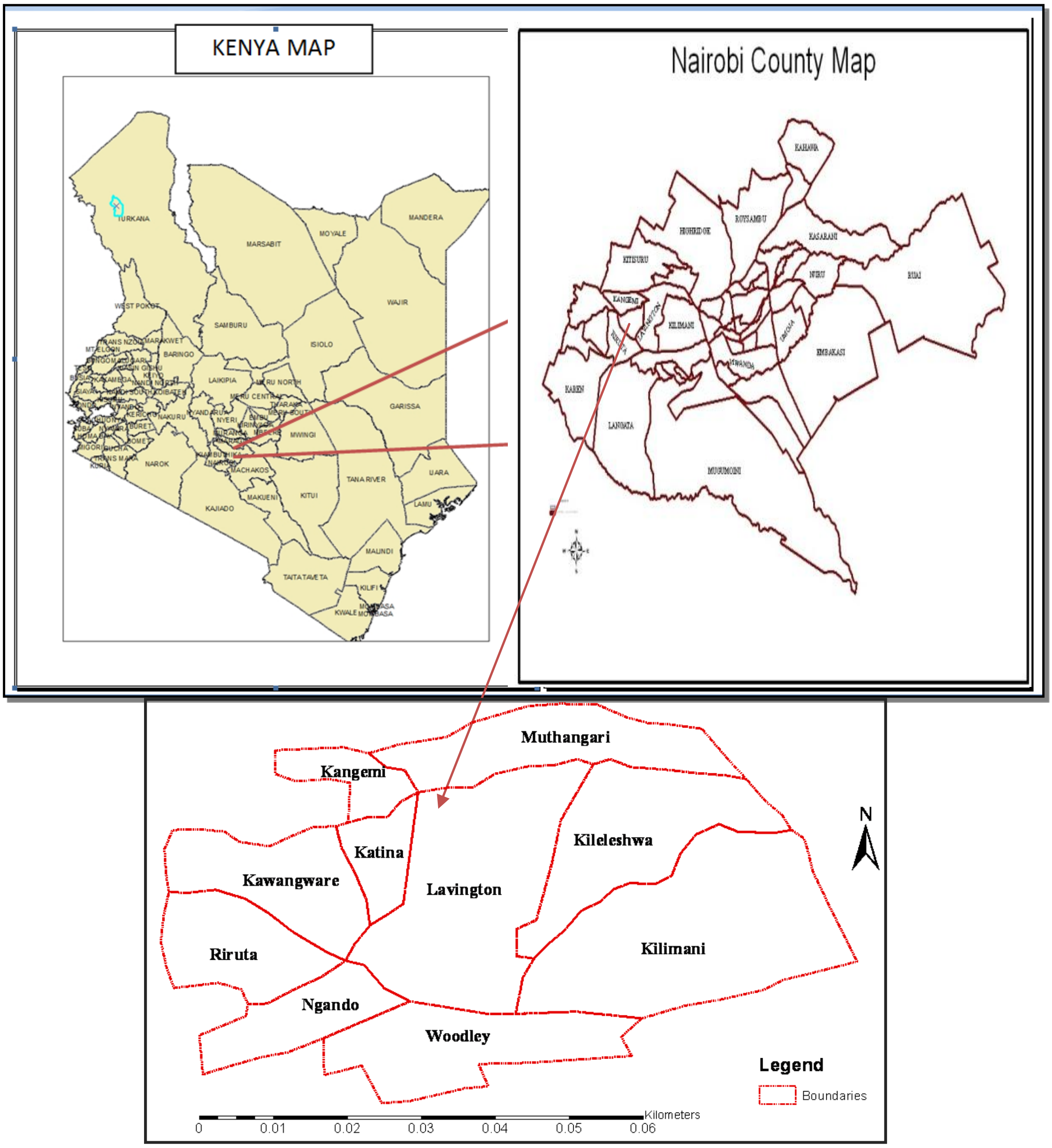


*Figure 1: Study area*

# CHAPTER 2: LITERATURE REVIEW

## 2.1 Current cadastral system

The current cadastral system in Kenya is mostly in analogue form. Only a small percentage of it in the Ministry of Lands that has been digitized. The analogue form includes parcel information in paper maps and conventional land registers holding information on location, tenure, use, encumbrances, ownership and distribution of land. This system is insufficient because of the large quantity of land records making access and retrieval of records a great challenge, (Kuria et al. 2005). Attempts are being made to computerise land records at the ministry with a focus on creation of a document imaging system. This is to provide compact storage, ease retrieval and improve document security. However, this falls short of digital cadastral recording, (Osundwa et al., 2010). Increased population and rural urban migration has led to an increasing demand in land, putting pressure on the efficiency of land management more critical in cities and urban areas. The need for a digital cadastre is high. To facilitate land administration and management, land registries ought to be computerised (Government of Kenya, 2008). The implementation of a digital cadastre in Kenya is faced with a myriad of challenges. A cadastre is "a parcel based, and up-to-date land information system containing a record of interests in land (e.g. rights, restrictions and responsibilities). It usually includes a geometric description of land parcels linked to other records describing the nature of the interests, the ownership or control of those interests, and often the value of the parcel and its improvements", (Van Osterom et al. 2011).

Individualization of property starts with subdividing the surface into property units using 2D boundaries making the basic entity of current cadastral maps the 'parcel', hence the 2D cadastral map. To ensure completeness and consistency, overlaps and gaps should not occur in 2D parcels. Despite parcel representation in 2D, someone with a right to a parcel is entitled to a space in 3D, i.e. a right of ownership on a parcel relates to a space in 3D that can be used by the owner and is not limited to just the flat parcel defined in 2D without any height or depth. If the right of ownership only applied to the surface, the use of the property would be impossible hence, from a juridical point of view cadastral registration always has been 3D. The issue arising is whether this traditional cadastral registration, based on the concept of a 2D parcel, is adequate for registering all kinds of situations that occur in the modern world or does cadastral registration need to progress to a 3D approach, (Jantien, 2004).

The FIG Bathurst Declaration(1999) concluded that "most land administration systems today are not adequate to cope with the increasingly complex range of rights, restrictions and responsibilities in relation to land". Since many existing cadastres are still based on a paradigm that has its origin centuries ago, this paradigm needs to be reconsidered and adjusted to today's world. Cadastral registration with respect to the issue of dimensions 2D and 3D ought to be considered with 3D property situations referring to situations in which different property units are located on top of each other. In 3D property situations, several users are using an amount of space (volume), which is bounded in three dimensions. In this case project the apartment units are the 3D property situations and registration of their rights is done under the LRA 2012.

The sale of apartments in Kenya was previously done under two laws, the RDA and the SPA. Under the RDA, an architect's plan of the building on which the units are serially numbered is registered and the units transferred to owners with reference to the registered plan while in SPA, Sectional plans consisting of a site and building location plan and a floor plan are registered and individual unit registers opened. The procedure for the survey and registration of apartments under the RDA and SPA is as summarized.

### 2.1.1 SPA

Necessary approvals (building and subdivision approvals) from relevant authorities are obtained.

- Survey of the buildings and parcel boundaries is done. It entails;
    - Floor plan survey; all unit dimensions are measured to the undecorated interior surfaces at floor level and made to 0.01m. Floor areas are calculated in square metres.
    - Site and building Location; Establishing beacons for the parcel boundaries to fixed boundary standards in accordance with the Survey Act and surveying the buildings within the parcel to a plottable accuracy using simple tacheometric and chain survey methods.
- Registration documents required are prepared which are sectional plans consisting of a site and building location plan and a floor plan.
- Sectional plans are registered and the parcel register is closed and a new one of each unit opened.

- On the payment of the prescribed fee, title deeds for each sectional property in respect of each unit are issued.
- No title deed is issued in respect of the common property but on registration of sectional plans, a register is opened for the common property - the register acts as a medium for recording matters such as the schedule for entitlement, the address for services of the notices on the Corporation and alteration of the bylaws.

### 2.1.2 RDA

An Architects building plan was approved by the relevant authorities, local authority.

- The approved plan with units serially numbered was approved and registered by the Registrar.
- The parcel on which the building stood was identified in the registration application document, (RDA, Form A).
- A certificate of registration, signed by the registrar, was endorsed on every registered document, showing the number of the document in the register and the date of registration.
- After registering of the architect's plan, any unit shown on it could be transferred with reference to the registered plan. The transfer instrument took the form of a lease or sub-lease in which each owner of a unit enters a covenant with the developer for the use and maintenance of common areas.
- A company is formed to manage the common property. The Company is incorporated by the filing of documents with the Registrar of Companies under the Companies Act.

RDA had fewer requirements making it faster and cheaper hence its preference to SPA. However, it had several shortcomings compared to the SPA.

The buildings registration as sub-leases under the parcel lease gave rights subordinate to the head lease tying the apartment owners to the head lessee for life. Head lease mistakes of omission or commission impacted on their ownership.Worse, the apartment holders had limitations when selling, charging or mortgaging their units since any such transaction must be tied to the head lease complicating building transactions.

Due to these shortcomings, Sectional Property Act has always been the best security for flats and apartments. It gives owners title deeds to their units; hence they can manage their obligations directly enhancing the safety of their registered rights. Any transactions on the building are done with the original title deed or lease certificate making it straight unlike under the RDA.

## 2.2 Aerial Photography

To cut back on the traditional manual surveying work in the SPA, geo-referencing can be done using remote sensing methods. These methods are, however, hindered by image quality, texture and cost.

Commercial satellite remote sensing provides spatial resolution from 0.40m which also very costly. Very High Spatial Resolution (VHSR) satellite imagery has enhanced the possibility to produce large scale topographic mapping but its effective use is restricted to panchromatic sensors (Demirel et. al., 2005). While the resolution may be sufficient for base mapping, it is not acceptable for modelling small details of a region, in this case buildings. The resolution makes it difficult to extract the buildings perfectly, leading to complicated corrections thereafter. Satellite imagery has weaker object resolving power because the same object is represented with relatively fewer pixels. A higher object density in image space makes it more difficult to separate a single object from surrounding ones and pixel mixing becomes more serious (Jin et al., 2005). As reported in Baltsavias and others, (2001), 1-meter high-resolution satellite imagery also leads to certain interpretation restrictions. About 15% of the building areas measured in aerial images could not be adequately identified in the satellite imagery.

National coverage aerial digital data sets with excellent spatial detail are routinely produced, such as every one or two years, for many countries (Groom et al, 2006). Kenya has continually being taking aerial digital data sets for mapping. Aerial photography offers much higher resolutions and is thus more appropriate for geo-referencing small objects. They provide a high resolution view of anything on the surface including trees, buildings and bridges.

Orthophotographs are aerial photographs which have been corrected for distortions caused by terrain relief and the camera. This is done by modeling the nature and magnitude of geometric distortions in the imagery. The traditional relief corrections done, differential rectification methods ignore the height of elevated objects like buildings, trees, bridges. The elevation differences lead to the pixel displacement making such objects distorted from their true position, hence the appearance of buildings as leaning and bent bridges. This makes it difficult to draw the outline of features and model them. Some information is also hidden from ground features such as roads due to the overshadowing decreasing interpretability of the image. Superimposition of vector data thus becomes nearly impossible limiting the use of the images with other datasets.

This calls for rectification of ortho-images using Digital Surface Models, DSM, resulting in true orthophotos. The emergency of true ortho-photographs makes it possible to draw the object outlines on the images directly. By integrating DSMs with True Ortho-photographs, it is possible to construct the terrain and building model accurately. Compared to traditional Ortho-images, True ortho-images have more advantages and the coordinates on the image are more precise. Perfect DSM will produce perfect true Ortho-images.

In the absence of DSMs, auto-manual extraction methods can be used. The building outlines can be extracted by image processing algorithms that identify the pixels linked together making a straight line of the border. In order to do this accurately, the process has to be done with some supervision, semi-automatically resulting in vector files with X, Y values.

### 2.3 Extraction of building footprints from aerial photographs

Building footprint in this project refers to the external outline of a building. The figure below illustrates the footprint.

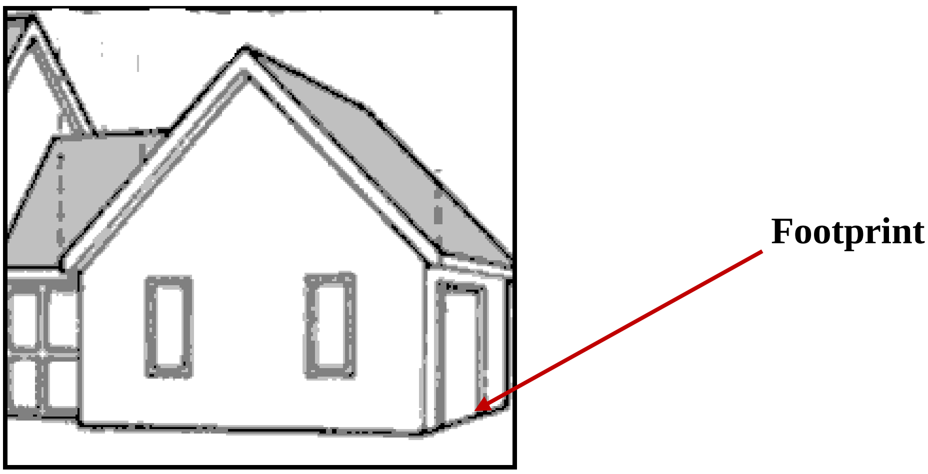


*Figure 2: Building footprint*

Building footprint extraction from aerial images has long been performed during updating digital maps and GIS database information. Due to its complexity and time-consuming manual interpretation, efforts have been made to speed up the process through automatic or semi-automatic procedures. A wide range of techniques and algorithms for detecting and delineating buildings have been proposed in order to automatically construct 2D or 3D building models from aerial imagery. Fully automatic building reconstruction techniques continue to be improved on. This is due to some unsolved issues: lack of flexibility to handle a large variety of building shapes; need to apply *ad-hoc* methods for decision making in the reconstruction process; presence of highly complex roof structures consisting of many small parts that not only result in over-generalized models, but may in fact cause algorithms to fail completely.

To date, building delineation and reconstruction from remote sensed imagery are still key issues, aiming at time and costs saving in cartographic production and updating. Full automatic systems in this field are difficult to implement in a single step, (Xiong, et al., 2006). This is due to difficulties in scene complexity and incomplete cue extraction and sensor dependency. Extraction methods continue to be selected according to data availability and level of detail to achieve. Sohn et al., (2007) and Lee et al. (2008) have categorized building detection techniques into three groups.

a) **Algorithms which use 2D or 3D information from photogrammetric imagery** (Mayer, 1999). The complexity of separating buildings from other objects increases with the increase of image resolution as high-resolution images contain more detailed information (Cheng et al., 2008), along with occlusions and shadows (Yong et 2008). The derivation of 3D information, for example, the depth information from stereo by multiple images is even more complicated (Vu et al., 2009). In addition, nearby trees of similar height also make the use of such derived range data difficult (Lee et al., 2008).
b) **Detection of building regions from LIDAR (Light Detection And Ranging) data**.; This is done by classifying the LIDAR points according to whether they belong to bare-earth, buildings, or other object classes (Lee et al., 2008). The introduction of LIDAR has offered a favourable option for improving the level of automation in the building detection process when compared to image-based detection (Vu et al., 2009). Oude Elberink (2008) has discussed a number of problems with building detection using LIDAR data and it has been shown that the use of raw or interpolated data can influence the detection performance (Demir et al., 2009). Moreover, there may be poor horizontal accuracy for building edges (Yong and Huayi, 2008) and it is hard to obtain a detailed and geometrically precise boundary using only LIDAR point clouds (Cheng et al., 2008). The quality of regularized building boundaries also depends on LIDAR resolution (Sampath and Shan, 2007).

c) **LIDAR data and photogrammetric imagery**. Photogrammetric imagery can provide extensive 2D information such as high-resolution texture and colour information as well as 3D information from stereo images. As a result, several authors have promoted an integration of LIDAR data and imagery as a means of advancing building detection (Rottensteiner et al., 2005; Yong and Huayi, 2008; Cheng et al., 2008; Demir et al., 2009).

Regarding performance evaluation, there is a lack of uniform and rigorous evaluation systems, and an absence of standards (Rutzinger et al., 2009). Evaluation results are often missing from published accounts of building detection (Yong and Huayi, 2008); the use of 1_2 evaluation indices only has characterized many studies (Demir et al., 2009; Vu et al., 2009). These indices are Per-area evaluation method which is a pixel based evaluation, where the raster representation of the detection results and the reference are compared. The second indice is per-object evaluation, where object are considered to be a true positive if a certain minimum percentage of its area is covered by objects in the reference (Rutzinger et al., 2009).

This project made use of photogrammetric imagery and as-built architectural buildings plans for building extraction. The proposed building extraction technique makes use of stereoscopic observations in digitizing the roof and base of each building. Extraction is done from the object view-point in 3D. Architectural plans are used to augment stereoscopic extraction compensating for areas where clear stereoscopic observation is not possible due to photo obstruction.

## 2.4 Modelling buildings

Building model reconstruction involves the derivation of building models. The primitives of the model here include the roof and the floor plans. Unlike in a 3D cadastre where only the outer boundary of the property unit is needed, detailed geometries of rooms were needed in this project so as to get plans of the interior of the buildings, floor plans. There are three ways to build 3D geometric primitives.

The first is extruding the existing 2D footprint to get a 3D outer boundary (Ying, Li, Guo, 2011; Ledoux and Meijers, 2011). The resulting shape corresponding to 3D solids can be constructed. During this process, the plans of the building or proposed buildings should be available and the elevation and height should be known ahead of the extrusion.

Secondly, a direct approach is to straightforwardly detect and recognize the valid 3D solids from given 3D boundary facets in imagery. This processing needs a strict algorithm with the support of proper geometry and topology (Ying, Guo, Van Oosterom, et al., 2011). Lastly, 3D cadastral models can be imported from 3D Building Information Models (BIM) or CityGML. These models are introduced from the National Building Information Model Standard, U.S.

CityGML is a common semantic information model for the representation of 3D urban objects that can be shared over different applications fields. It is based on a number of standards from the ISO 191xx family, the Open Geospatial Consortium, the W3C Consortium, the Web 3D Consortium, and OASIS. CityGML supports different Levels of Detail (LOD), see figure 3 which are required to reflect independent data collection processes with differing application requirements.. Further, LODs facilitate efficient visualization and data analysis. The multiscale model with 5 well-defined consecutive Levels of Detail (LOD) are:

- ❖ LOD0 – regional, landscape
- ❖ LOD1 – city, region
- ❖ LOD2 – city districts, projects
- ❖ LOD3 – architectural models (outside), landmarks
- ❖ LOD4 – architectural models (interior)

The coarsest level LOD0 is essentially a two and a half dimensional Digital Terrain Model, over which an aerial image or a map may be draped. LOD1 is the well-known blocks model comprising of prismatic buildings with flat roofs. In contrast, a building in LOD2 has differentiated roof structures and thematically differentiated surfaces. Vegetation objects may also be represented in LOD2. LOD3 denotes architectural models with detailed wall and roof structures, balconies, bays and projections. High-resolution textures can be mapped onto these structures. In addition, detailed vegetation and transportation objects can be components of a LOD3 model. LOD4 completes a LOD3 model by adding interior structures for 3D objects which includes rooms, interior doors, stairs, and furniture.

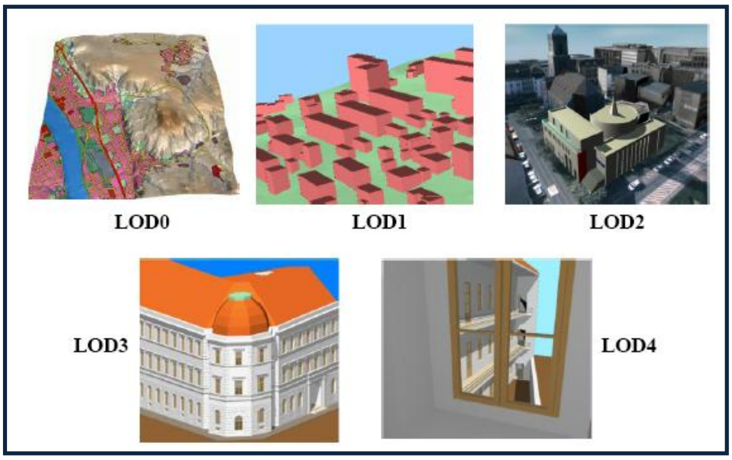


*Figure 3 : The five levels of detail defined by CityGML (source: IGG Uni Bonn)*

CityGML LOD4 was used in this project. Building floor plans were extruded using the floor heights in the as-built building plans.

### 2.5 Visualization

It is not easy to use traditional visualization technologies of 2D maps to depict 3D cadastral objects. Without visualization of 3D objects, 3D property cannot be represented in a 3D cadastral map which shows the location of objects and properties in space. The visual obstacles of physical entities among different geo-spaces causes visualization difficulties. The aim of visualization is to show the location, as well as the context of 3D cadastral objects and highlight them.

There are many differences between 3D cadastre and virtual city/architecture, and emphasis is shifted from urban simulation to the distribution of 3D land space, 3D property units and other cadastral objects. Visualization for architecture focuses either on the holistic view and harmonic fusion of the architectures surrounding or on the functional division or the configurations of the interior of the architectures. The visualization for architectures emphasizes the reality of architectural entities and their functions, and stresses the visual effects of the exterior surface or interior construction. Objects for architecture visualization are walls, doors, windows and so on. Other visualizations, such as urban simulation and virtual city, focus on visual simulation of the exterior "skin" of the city. They pay more attention to the facade surfaces of the models and to photo textures for photorealistic looks, not to the interior "units" under the skin.

However for 3D cadastre, the norm is to describe the precise boundary of property and cadastral objects focus on the geo-space under the cadastral rights, despite the fact that this geo-space may be delimited by the physical walls of architectural properties. The visualizations of 3D cadastre illustrate the distribution of occupation and partition of land space and urban space in order to give clear ideas for users or to support decision-making for the government. The core unit for a cadastral object is its 3D geometry as well as its corresponding parts. According to the relationships between the boundaries and physical entities, there are two types of 3D cadastral objects: physical objects and non-construction-based cadastral objects. The geometric boundaries of the 3D cadastral objects are the statutable or legal geographic surfaces, which can be part of realistic/physical entities or can even be legal "blank" or "virtual" surfaces. Accurate three dimensional descriptions of cadastre and property has become an important need of governmental management and citizens' rights. (Shen Ying et al., 2012).

# CHAPTER 3: MATERIALS AND METHODS

## 3.1 Materials

### 3.1.1 Data

Data was sourced from various sources. Below is a summary of the data used and its source.

*Table 1: Data used in the project and its source*

| **Data** | **Source** | **Characteristics** |
|---|---|---|
| Orthophographs of Nairobi | Geomaps | Digital, taken in 2012, projection UTM 37s Arc1960, 10cm |
| Approved RDA Building Plans | Lands Department | Hardcopy,- approved 2006 |
| Survey Plans | Survey of Kenya | Hardcopy, Lavington area parcel boundaries |
| Administrative Boundaries | Survey of Kenya | Shapefiles |
| Road network | KenHa | Shapefiles |

**Orthophotographs**

The images were taken in 2012. They are coloured and have a spatial resolution of 10cm. They covered the whole of Nairobi. A boundary shapefile of Masiwa sub-location (Lavington) was used to clip the orthophotos to the area of interest.

**Architectural building plans**

These are building plans approved in 2006 by the registrar under the RDA, see appendix A. They plans were obtained in hardcopy plotted at a scale of 1: 100 from the department of lands, Ardhi house. The buildings lie on parcel number 330/268/1-2 Kingara Road.

**Survey Plans**

The parcel boundaries used in this study were drawn based on several hardcopy survey plans obtained from the Survey of Kenya. These plans depict the boundaries in 2D and are plotted at a scale of 1:500, see appendix B.

### 3.1.2 Tools

**a) <u>Hardware:</u>**

The hardware used in the project included:

- A personal computer and a digital photogrammetric workstation

**b) <u>Software:</u>**

The software used in the project included:

- Erdas Imagine LPS
- ArcGIS 10
- AutoCAD Land Development

## 3.2 Methods

The flowchart below shows the processes undertaken for data processing in this study.

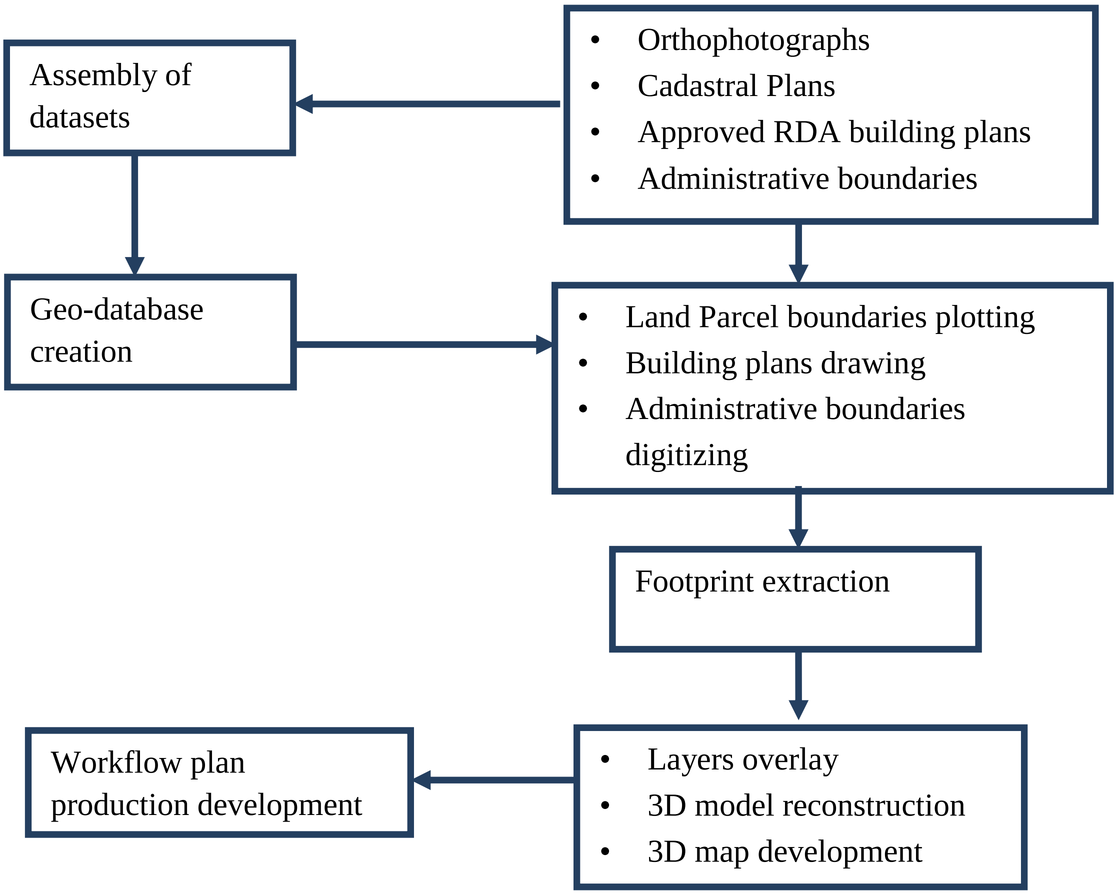


*Figure 4: Summary of the data processing*

### 3.3 Data Preparation

The data collected was preprocessed to turn it into a form suitable for manipulation and intergration. The preprocessing steps used were as follows;

### 3.3.1 Creation of a Geodatabase

A file geo-database was created using Arc Catalog and saved as Land.mdb. Feature datasets such as cadastral, administration, infrastructure, raster and classes in them were created in the file geo-database. Data was added to the feature classes and indexes built for the appropriate fields to improve the query performance. Joins and relates between feature classes were made and privileges granted and revoked on the feature datasets, and feature classes for other database users. Figure 5 below the Geo-database.

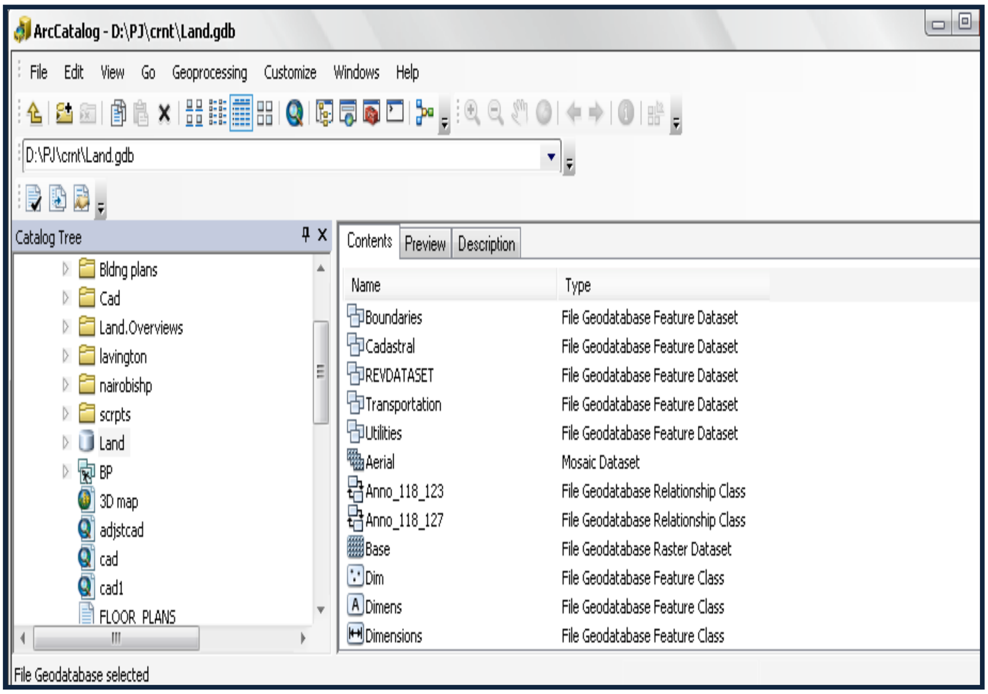


*Figure 5: Land Geo-database*

### 3.3.2 Survey Plans

The plans of the land parcels were obtained in hardcopy from Survey of Kenya. As the boundaries were needed in digital format, they were plotted in ArcMap. The plans were however in Cassini Coordinate system and so had to be transformed into the system in use, UTM 37s Arc1960. This was done in ArcMap. Figure 6 shows the resulting parcel boundaries plot.

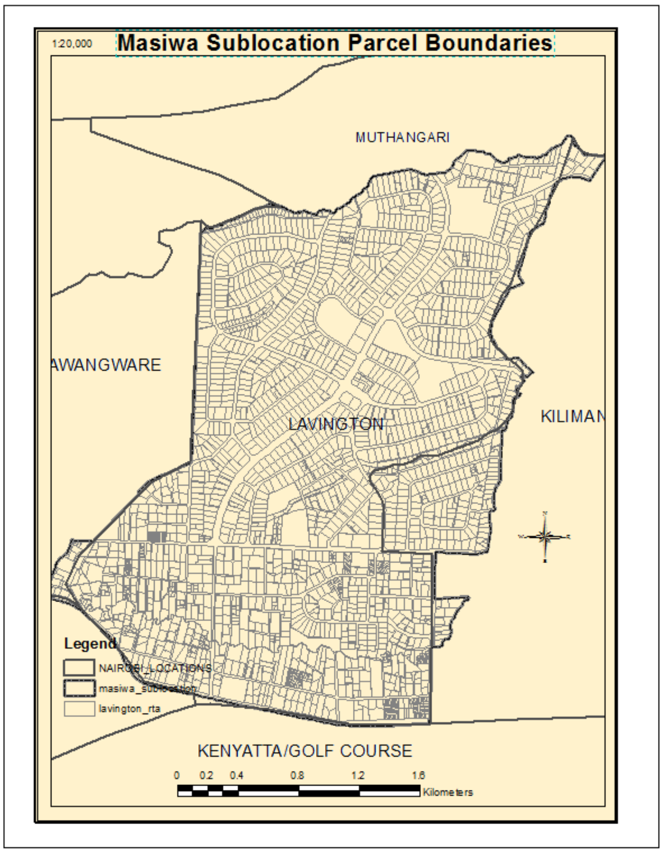


*Figure 6: Lavington Cadastral boundary Map*

### 3.3.3 Layers Overlays

An overlay of the parcel boundaries on the orthophotos was done. An apparent lateral shift on the orthophotos could be observed as shown in figure 7. This was further confirmed after overlaying the roads layer. The shift occurred during the orthophoto production process. This shift was adjusted by aligning the orthophotos with the parcel layers.

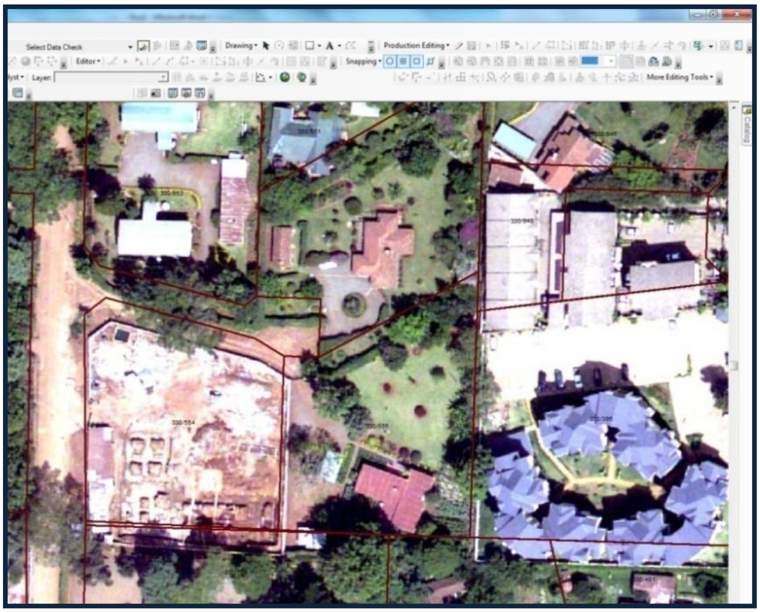

*Figure 7:Orthophoto shift*

### 3.3.4 Architectural Building Plans

These were in hardcopy and were thus plotted to convert them to digital format. The building plans were drawn using AutoCAD. AutoCAD Map extension was then used to export the drawings in dwg format to a shapefile, which was then imported into the geo-database. Figure 8 shows the AutoCAD plotted floor plans.

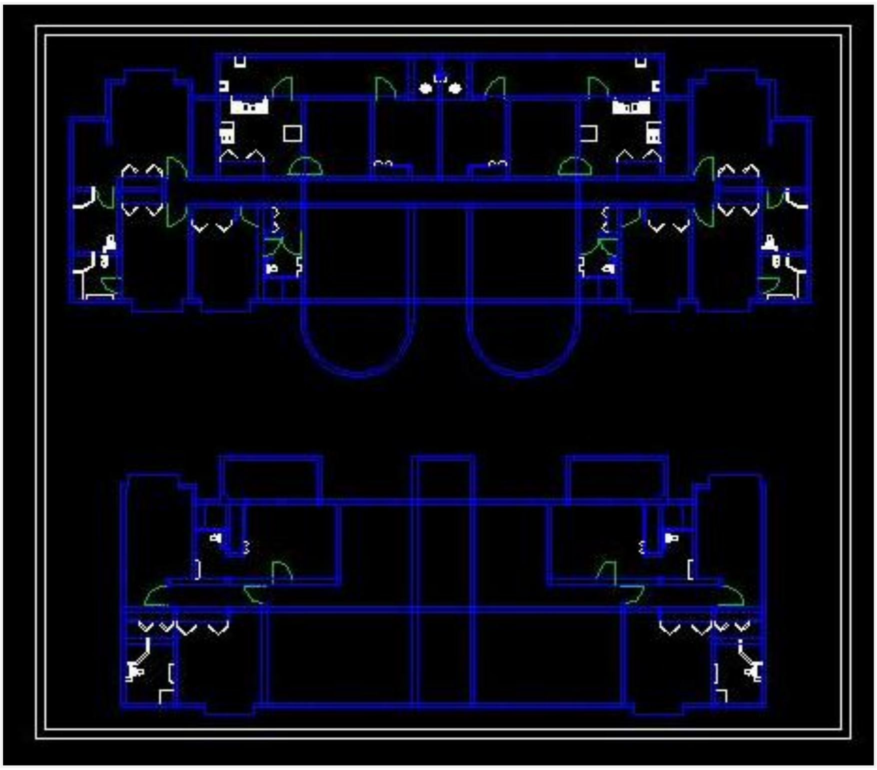

*Figure 8: AutoCAD plotted floor plans*

## 3.4 Building Footprint extraction

Stereoscopic viewing was used in extraction of building footprints. This was done using Erdas Imagine LPS software on a Digital Photogrammetric Workstation. Stereo pairs of photos were observed and the visible ground wall positions extracted.

However, not all corners were visible due to obstructions from shadows, and other overhanging buildings. In these cases, a second extraction method was employed.

It involved digitising of the rooftops from the Orthophotographs in 2D and using the architectural rooftop structural designs and the building height, the ground positions were derived. Figure 9 summarises the footprint extraction process and the resulting footprints.

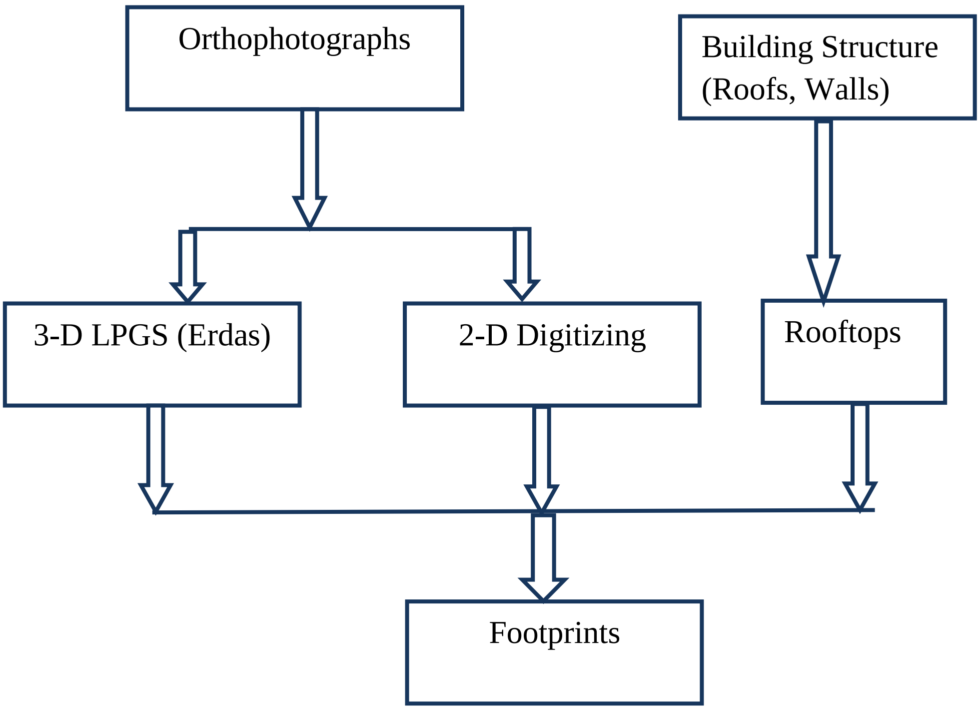


*Figure 9: Footprint extraction process*

*Figure10a: Digitized rooftop*

*Figure10b: Extracted footprints*

### 3.5 Building Model reconstruction

Building model reconstruction is the derivation of building models which are in vector format. It involves the construction of 3D building models in the form of geometric 3D primitives while maintaining the building boundary accuracy.

Reconstruction was done by extruding the existing 2D floor plans to get a 3D buildings summarised in figure 11. 3D features were created from the 2D floor plan feature class. The floor heights provided the Z heights with the vertical datum being the ground floor at 0 m. Subsequent floor heights were incremented by the ceiling-floor height, 2.7m and a ceiling width of 0.2 m.

The building floor plans were overlayed and using the floor heights specified in the plans 3D feature class, extrusion was done to get a 3D outer boundary. From the resulting shape, 3D solids were constructed. This was done in ArcScene resulting in a complete 3D building with interior unit structure visible as shown in figure 11 below. ArcScene 3D modelling could only be done for solids and since the interior of the building was also of interest AutoCAD 3D modelling was done. Here building wireframe models were created which enabled a walkthrough inside the building.

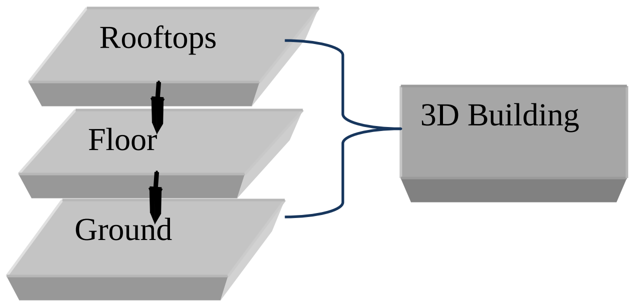


*Figure 11: Building modelling process*

### 3.6 Workflow construction

A workflow is a set of connected procedures used in producing something. A workflow was constructed to standardise the plan production process. It was aimed at ensuring that the produced plans were of a uniform set standard. The workflow was constructed using ArcGIS workflow manager. It involved connecting the procedures in map plan printing, from feature selection to plan printing. The resulting workflow is as shown in figure 12 and its construction of involved the following processes.

### 3.6.1 Building dimensioning

Dimensions are a special kind of geo-database annotation for showing specific lengths on a map. Dimensions indicated the length of a side of a building or land parcel and the distance between features such as parcel boundary and the corner of a building.

A dimension feature class was created and the building interior dimensioning done in ArcMap. The dimensions were converted to annotations to enhance their representation by scaling each dimension as per the size of the feature it lied on.

The dimensions were attributed into two groups, building interior dimensions and building-parcel dimensions. This was so as to aid in the SPA plan production having floor plans and site location plans with offsets from the parcel boundaries.

### 3.6.2 Template construction

Templates for the SPA plans were constructed as per the standard plan sizes used and saved in ArcMap. Standard formats used were those employed in the survey plan printing. These were form 4 and form 3.

### 3.6.3 Printing

A printing format was set up and applied to the map document. This was done in ArcMap using the Data Driven Pages tool. Printing option, paper size, extent and scale were set in this format. It enabled auto-splitting and indexing of plans into several sheets. On selection of features to print, the software determined the number of pages required to fit the features and printed the plan in a series of indexed sheets, see figure 12.

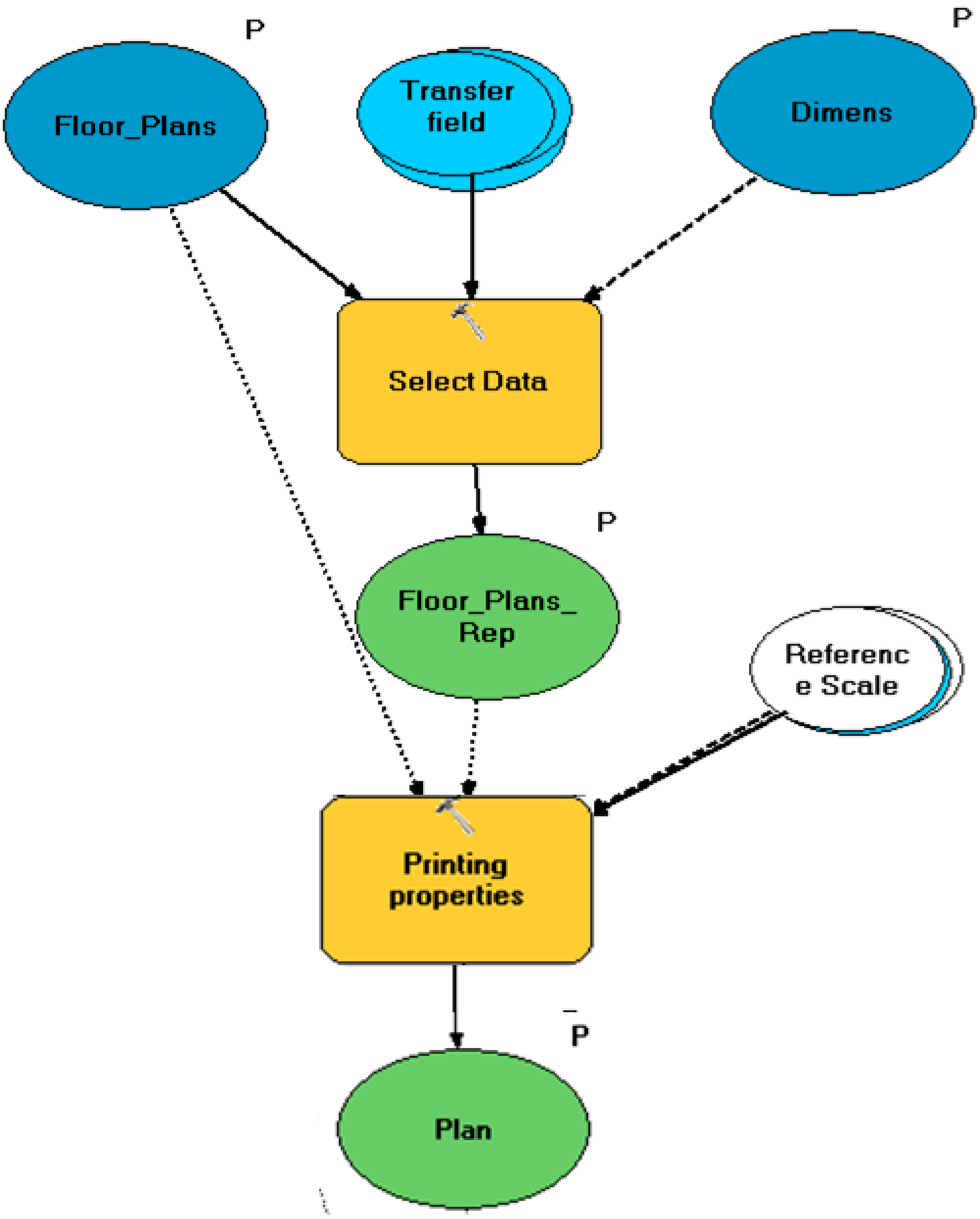


*Figure 12: Workflow flowchart*

# CHAPTER 4: RESULTS AND ANALYSIS

## 4.1 Outputs

The objectives set out were achieved. They include;

a) Building footprints extracted from aerial imagery.

The figure 13 shows the extracted footprints.

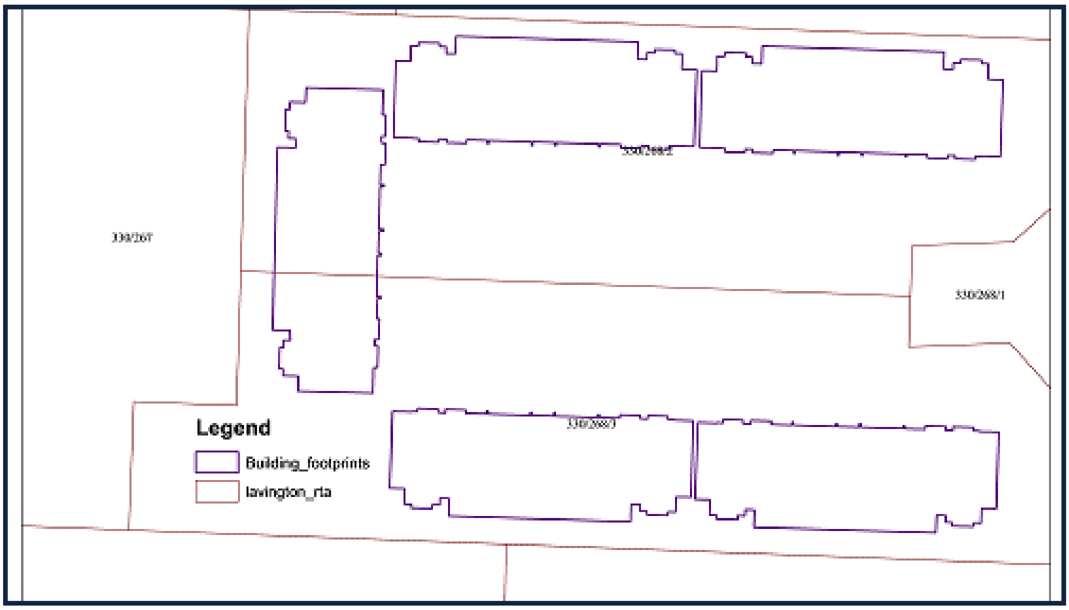


*Figure 13: Building footprints*

b) Overlay of extracted footprints with architectural building plans.

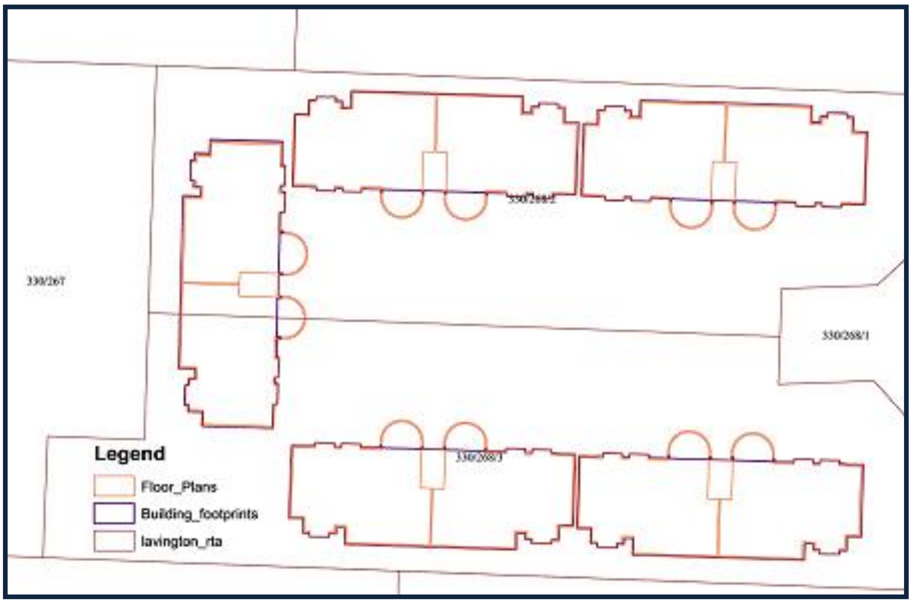


*Figure 14: Geo-referenced building floor plans*

c) 3-D building models.

There were two models generated; a solid model using ArcScene and a wireframe model using AutoCAD.

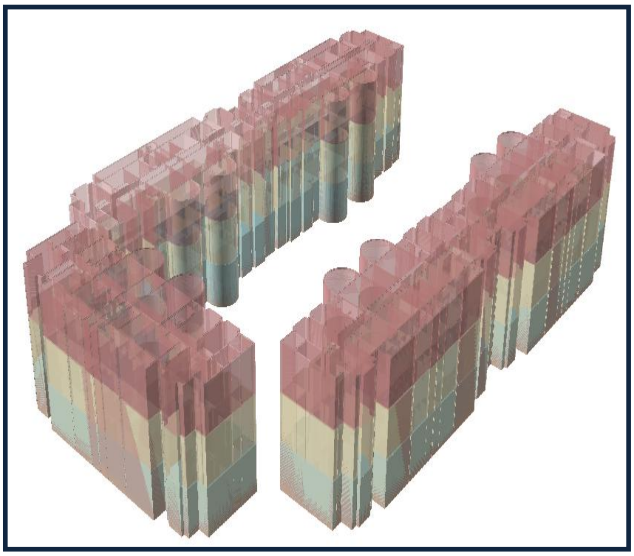

*Figure 15a: ArcScene solid models*

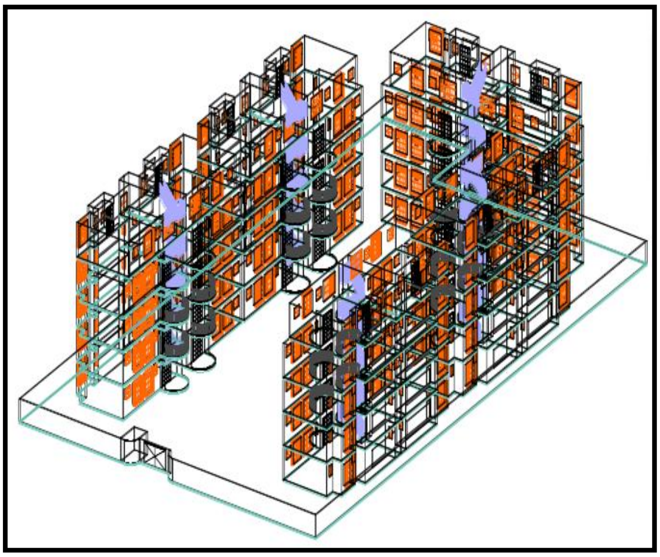

*Figure 15b: AutoCAD wireframe models*

d) Sectional Plans.

The plans produced were sectional plans, site and location plans. These are attached in appendix 3.

## 4.2 Analysis

### 4.2.1 Parcel boundaries

The cadastral boundaries were plotted and it was observed that some of the parcel boundaries were not coinciding at the edges as would be expected; abutting parcel survey plans had differing corner beacon coordinates. This is illustrated in figure 16. This could be due to a number of reasons; use of different coordinate systems and errors occurring during transformation, long traverses that were not adjusted correctly or an error in the initial control survey of the area block. This can be solved by adopting the ground boundary position and adjusting survey plans and titles accordingly. Another solution could be arbitrating between the abutting parcel owners on the boundary position to adopt. This overlap is usually ignored by most surveyors. There have been no efforts on addressing this as it exists not only in Lavington but also in most parts of the country.

It was also noted that the building plans obtained didn't belong to one parcel as stated in the building plans but to three parcels with one apartment building actually lying in two parcels. From the survey plan, there seems to be no evidence of an amalgamation done hence this can be assumed to be negligence on the part of the approving authorities. Figure 17 shows the building positions on the survey plans.

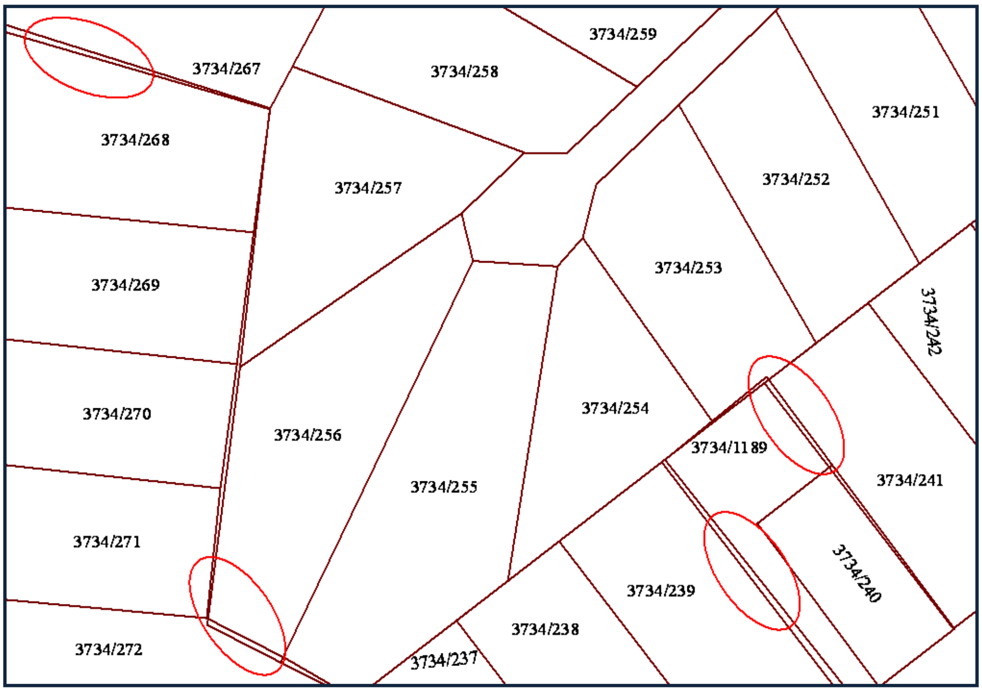


*Figure 16: Non-coinciding parcel boundaries*

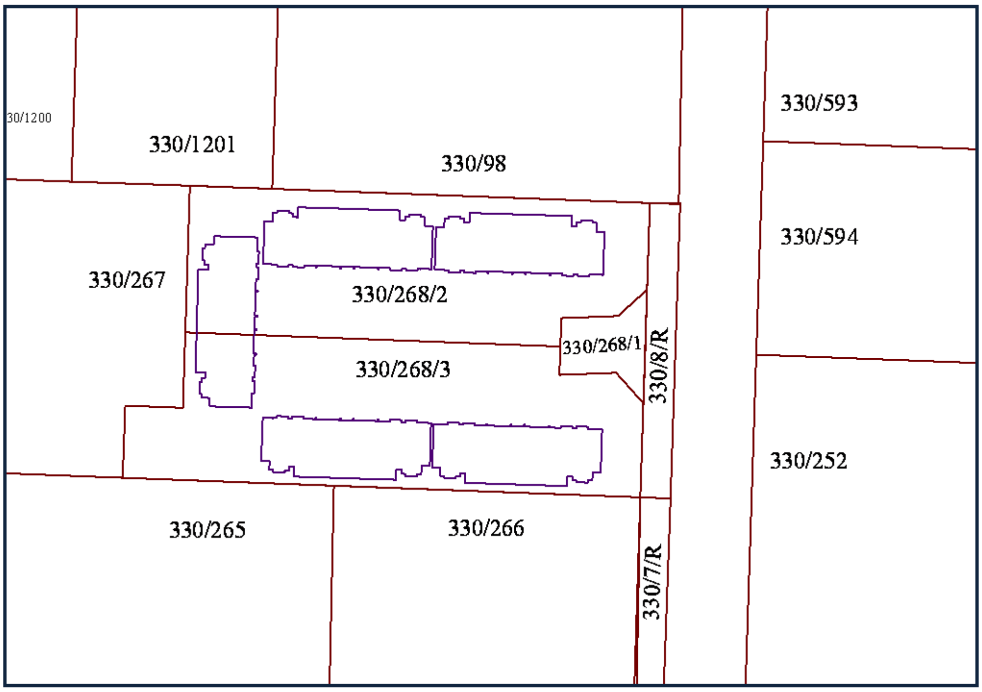


*Figure 17: Apartment buildings occupying 3 parcels*

### 4.2.2 Accuracy

Accuracy checks were done on the extracted building footprints and building units to establish the positional accuracy. The parcel boundary positioning is beyond the scope of this project and with nothing done on the boundary, no accuracy assessment can be done.

Ideally, the parcel boundary accuracy should be as stipulated for fixed boundaries. Beacon position identification and possible reestablishment are to be done as per the Survey Act, (Laws of Kenya, Cap 299) and meet the fixed boundary accuracy standards of +/- 3cm.

The check used for the positional accuracy of the extracted footprints was building-floor plan overlay.

### 4.2.3 Building-floor plan

The floor plans generated from the final building plans were overlayed onto the extracted footprints providing a geometrical shape check for the footprints. The building plan-footprint difference was found to have a maximum variance of 15cm. This is building position accuracy acceptable as per the CityGML guidelines of LOD 4 where the absolute 3D point accuracy should be +/- 20 cm and the accuracy of sectional plans boundaries is stipulated by the plotting scale. The achieved variance is thus within both definitions. Table 2 shows the positional comparison obtained from footprints and building plans after geo-referencing and the variance as visualized in figure 18.

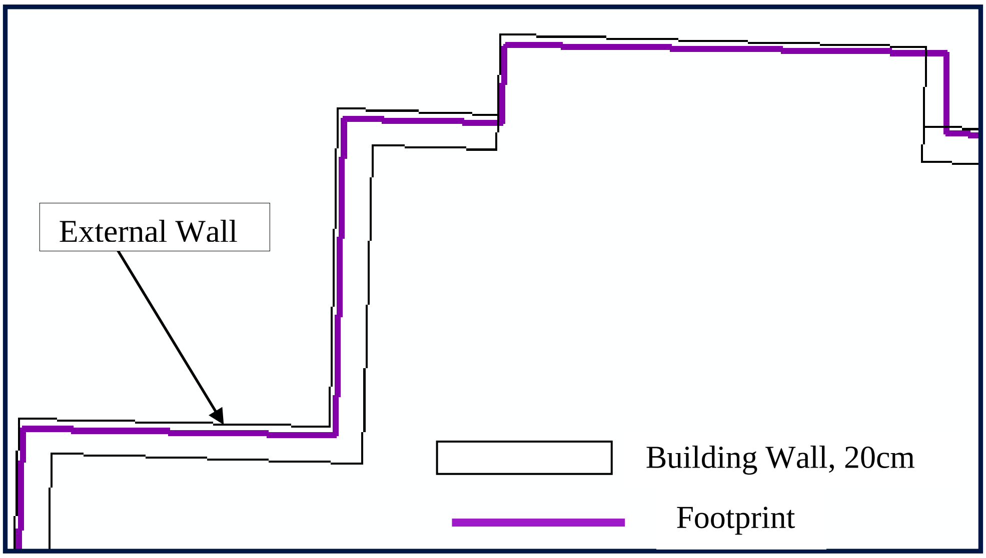


*Figure 18: Footprint building plan variance*

*Table 2: Footprint- plan comparison*

| Building | Plot_No | Foot_prints | | | Building_plan | | | Variance | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Area | X_Centroid | Y_Centroid | Area | X_Centroid | Y_Centroid | X | Y | Area |
| 101 | 330/268 | 448.168 | 250779.22 | 9857564.41 | 445.251 | 250779.22 | 9857564.423 | -0.005 | -0.015 | 2.9 |
| 102 | 330/268 | 448.167 | 250742.87 | 9857565.68 | 449.367 | 250742.91 | 9857565.642 | -0.042 | 0.038 | -1.2 |
| 103 | 330/268 | 448.167 | 250718.30 | 9857549.1 | 450.863 | 250718.35 | 9857549.116 | -0.044 | -0.012 | -2.7 |
| 104 | 330/268 | 448.167 | 250742.47 | 9857523.54 | 459.287 | 250742.46 | 9857523.376 | 0.012 | 0.161 | -11 |
| 105 | 330/268 | 448.167 | 250778.60 | 9857522.21 | 447.157 | 250778.66 | 9857522.153 | -0.061 | 0.058 | 1 |

### 4.2.4 Non-vertical buildings

Not all buildings are vertical. For a leaning building, see figure 19, footprints will be extracted stereoscopically like that of vertical buildings since the vertices are visible from different views. Modeling of the building can then be done using the floor plans and heights available in the as-built plans.

*Figure 19: Leaning building*

# CHAPTER 5: CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

The project was successfully completed and the objectives were met. Geo-technologies were used in place of the conventional survey procedure currently used in Sectional Properties, tape measuring. This was accomplished by using extracted building footprints for geo-referencing building corners and their floors and as-built plans for obtaining unit dimensions and areas replacing the manual  room to room tape measuring method currently in use.

Use of this method will make sectional properties survey less tedious and faster. Conventional room by room measurements and summation to get unit dimensions is replaced by using geo-referenced as-built plans making the process faster, cheaper and more accurate. The constraint to using this method could obtaining as-built building plans due to their scarcity. This is because despite it being mandatory for architects to submit as-built plans after construction, not everyone submits them.

The project utilized remote sensing and GIS. Remote sensing was used for geo-referencing and GIS for storage, retrieval, manipulation and visualization. It became apparent that 3D visualization in ArcGIS is restricting. Only solids could be modeled and as the modeling required showing the building interiors, this could not be achieved with ArcGIS only. AutoCAD 3D modeling offered more room for improved building visualization including the interiors.

## 5.2  Recommendations

The system uses python as the programming language for customization. More customization can be done to ease operations and integrate 3D visualization with the 2D ArcMap representation. An integration of AutoCAD with ArcGIS would offer more flexibility in visualization of 3D models.

The National Housing Corporation should enforce regulations on submission of as-built plans and liaise with the Ministry of  Lands for approval of these plans.

The system can be used in other government departments for various purposes. Though developed to help the SPA survey process, the real property representation in 3D can be used in solving other urban related problems. There are technical problems that still need more research, most pressing being accurate building geo-referencing in heavily built up areas such as towns and variance relation of submitted plans and the as-built plans.

To completely implement 3D cadastre, both technical problems and the lack of legal structures in place need be addressed. Setting up legislation and standards on 3D cadastres and modeling would help guide future work.

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## 7.0 APPENDICES

Appendix A: Approved building plans

Appendix B: Land parcel survey plan

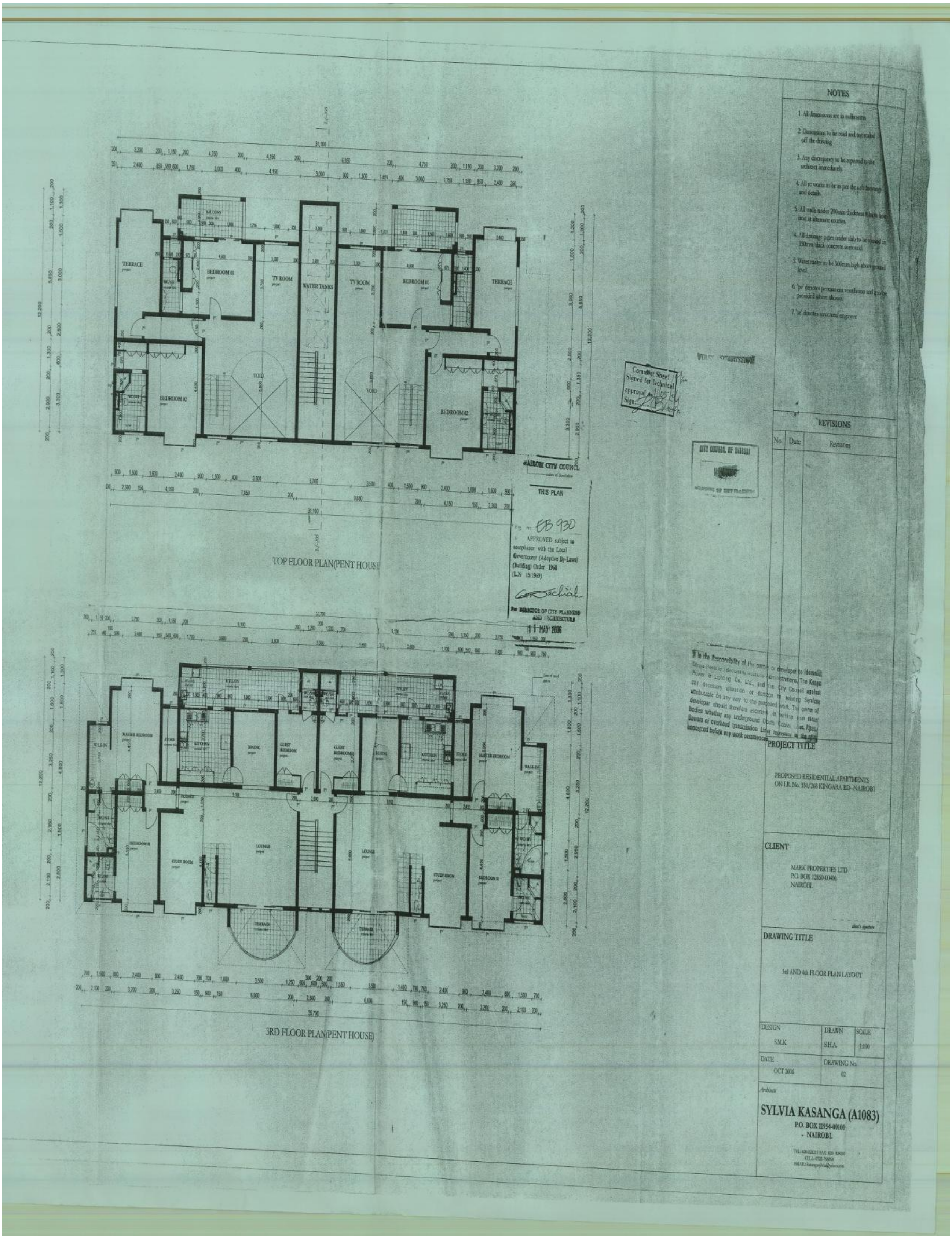
Appendix C: Sectional property plans

Appendix C1: Sectional Plan

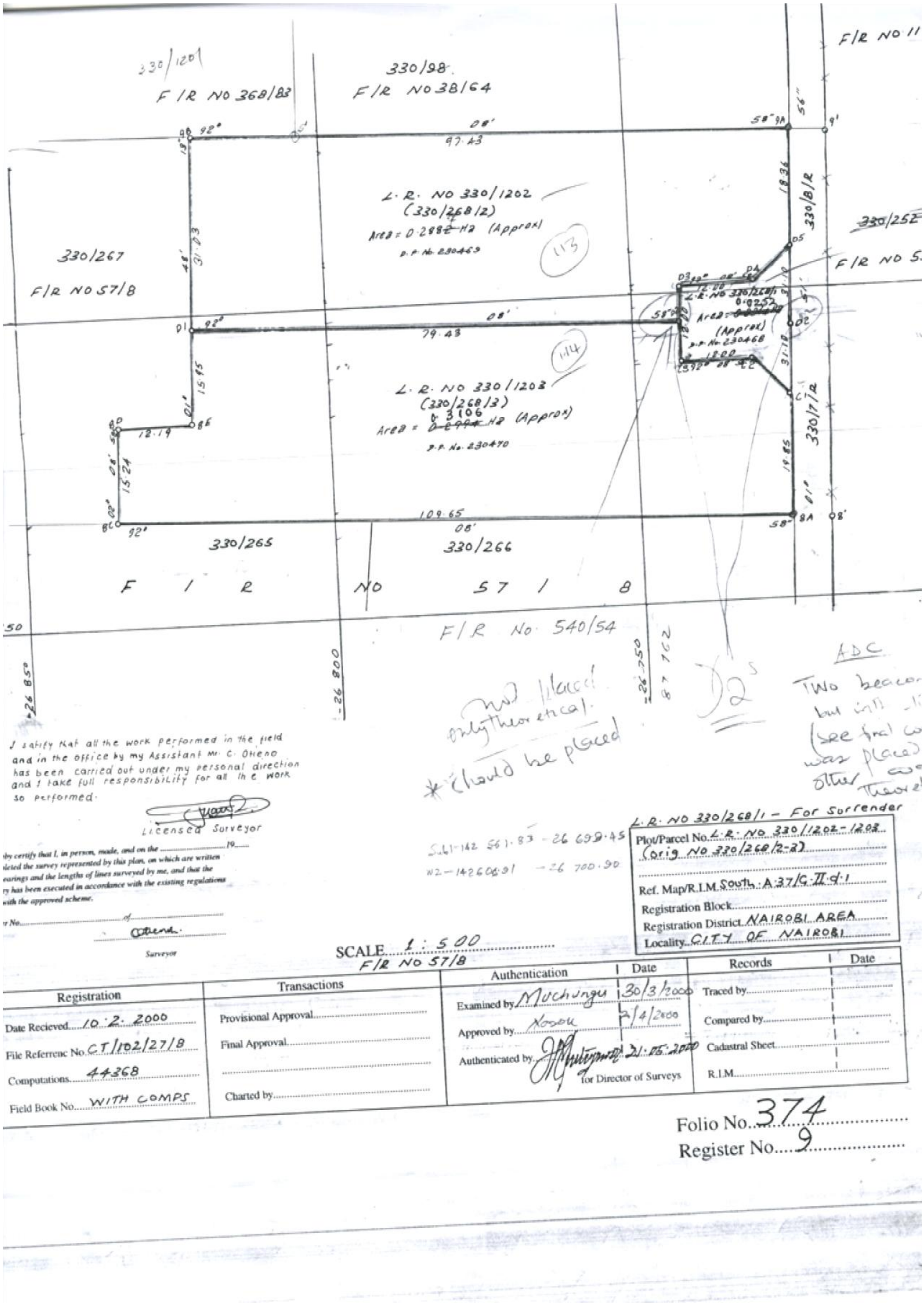
Appendix C2: Location Plan

Appendix C3: Site Plan

# Appendix A: Approved building plans

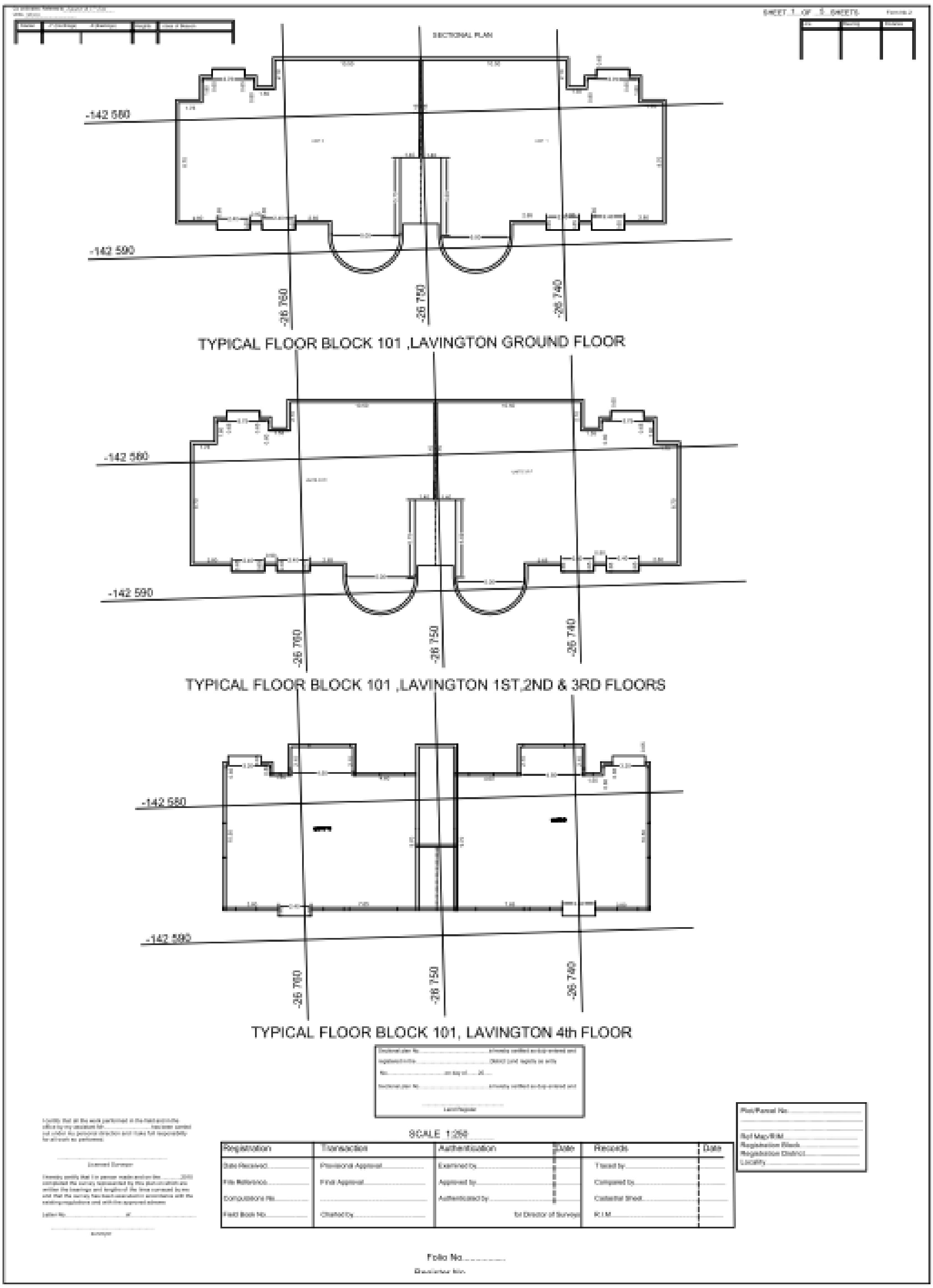


## Appendix B: Land parcel survey plan

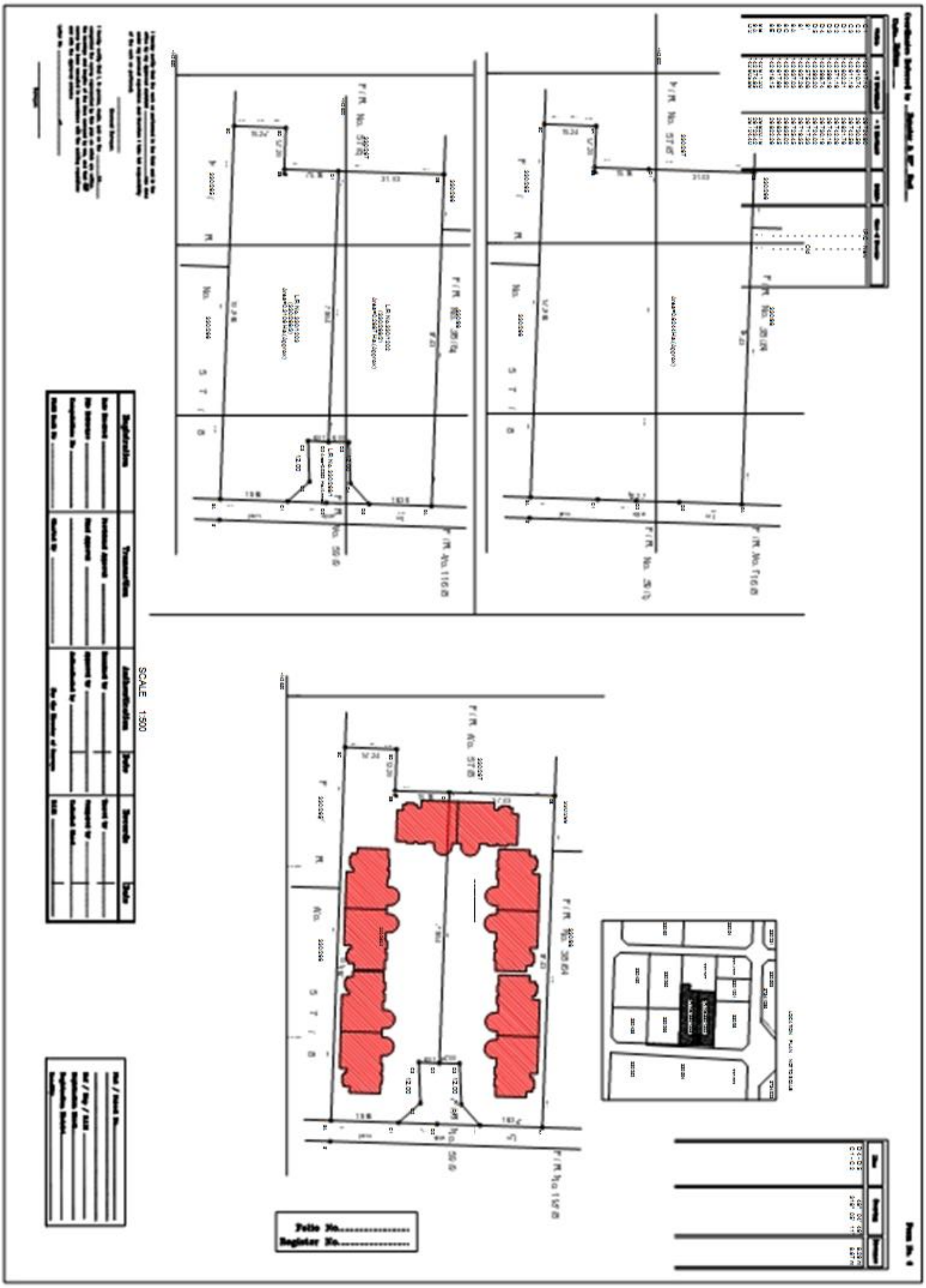


## Appendix C: Sectional property plans

### Appendix C1: Sectional Plan



## Appendix C2: Location Plan



## Appendix C3: Site Plan